

No. II

1927

THE JOURNAL

OF THE

IRON AND STEEL INSTITUTE

VOL. CXVI.

EDITED BY

GEORGE C. LLOYD

SECRETARY



PUBLISHED AT THE OFFICES OF THE INSTITUTE
28, VICTORIA STREET, LONDON, S.W. 1.

1927

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PREFACE.

THE present volume of the *Journal of the Iron and Steel Institute* contains the fifteen papers presented at the Autumn Meeting held in Glasgow, together with the discussion and correspondence to which they gave rise. It also contains a paper by Dr. W. Rosenhain, F.R.S., and Messrs. R. G. Batson and N. P. Tucker, originally presented at the Annual Meeting in 1926, with the discussion and correspondence relating to it; its publication had been deferred pending the completion of additional experiments by the authors. The functions held and the works visits made during the meeting in Glasgow are reported. Biographical notes of the careers of deceased members are to be found under "Obituary Notices."

Section II. contains the usual notes on the progress of the home and foreign iron and steel industries as reported in the proceedings of Scientific and Technical Societies and in the technical press, together with notices of new books presented to the Institute and a bibliography of the principal works dealing with the metallurgy of iron and steel and allied subjects which have appeared during the last half-year. At the end is inserted a list of the British Standardised Steel Samples issued jointly by the Iron and Steel Institute and the National Physical Laboratory, showing where and on what terms the samples are available.

28 VICTORIA STREET, LONDON, S.W. 1.

December 31, 1927.

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ABBREVIATIONS USED IN TEXT.

Å	Ångström unit.	hr.	hour(s).
a.c.	alternating current(s).	in.	inch ; inches.
amp.	ampère(s).	in.-lb.	inch-pound(s).
amp.-hr.	ampère-hour(s).	K.	absolute temperature (scale).
atm.	atmosphere(s) (pressure).	kg.	kilogramme(s).
Bé.	Baumé (scale).	kg.-m.	kilogramme-metre(s).
B.H.P.	brake horse-power.	km.	kilometre(s).
B.O.T.	Board of Trade.	kva.	kilovolt-ampère(s).
B.th.u.	British thermal unit(s).	kw.	kilowatt(s).
B.T.U.	Board of Trade unit(s).	kw.-hr.	kilowatt-hour(s).
B.W.G.	Birmingham wire-gauge.	lb.	pound(s).
C.	centigrade (scale).	L.-F.	low-frequency.
cal.	calory ; calories.	m.	metre(s).
c.c.	cubic centimetre(s).	m.-amp.	milliampère(s).
c.d.	current density.	m.-volt	millivolt(s).
cg.	centigramme(s).	max.	maximum.
c.g.s.	centimetre - gramme - second unit(s).	mg.	milligramme(s).
cm.	centimetre(s).	min.	minimum ; minute(s).
coeff.	coefficient.	mm.	millimetre(s).
const.	constant(s).	m.m.f.	magnetomotive force(s).
c.p.	candle-power.	N.	normal (solution).
cu.	cubic.	N.T.P.	normal temperature and pressure.
cwt.	hundredweight(s).	O.-H.	open-hearth.
d.c.	direct current(s).	oz.	ounce(s).
dg.	decigramme(s).	p.d.	potential difference.
diam.	diameter(s).	R.	Réaumur (scale).
dm.	decimetre(s).	r.p.m.	revolutions per minute.
e.m.f.	electromotive force(s).	sec.	second(s).
F.	Fahrenheit (scale).	sp. gr.	specific gravity.
ft.	foot ; feet.	sq.	square.
ft.-lb.	foot-pound(s).	temp.	temperature.
grm.	gramme(s).	v.	volt(s).
H.-F.	high-frequency.	va.	volt-ampère(s).
H-ion	hydrogen-ion.	w.-hr.	watt-hour(s).
H.P.	horse-power.	yd.	yard(s).
H.P.-hr.	horse-power-hour(s).	°	degree(s).

SECTION I.

*MINUTES OF PROCEEDINGS
AND PAPERS OF
THE IRON AND STEEL INSTITUTE.*

AUTUMN MEETING

1927.

Editorial assistance has been given by A. E. CHATTIN, B.Sc. (Hons. Met.),
Assistant Secretary, in the preparation of this Section.

MINUTES OF PROCEEDINGS

AND

PAPERS AND DISCUSSIONS

AT THE

GLASGOW MEETING, 1927.

THE AUTUMN MEETING OF THE IRON AND STEEL INSTITUTE was held in the Rooms of the Royal Technical College, Glasgow, on Tuesday, Wednesday, and Thursday, September 20, 21, and 22. At the opening session the members assembled in the Examination Hall of the College, where they received a welcome to the City of Glasgow and the West of Scotland district by Mr. John Craig, C.B.E., President of the West of Scotland Iron and Steel Institute, Chairman of the Reception Committee (Member of Council of the Iron and Steel Institute), by the Right Hon. Lord Provost, and by Mr. James Morton, President of the Glasgow Chamber of Commerce. The Chair was taken by Mr. JOHN CRAIG.

The LORD PROVOST OF THE CITY OF GLASGOW (Mr. David Mason), on rising to welcome the members and their ladies, said that he was delighted that the Institute had honoured Glasgow by the holding of its Autumn Meeting in that city, and in the name of the Corporation and the citizens he extended to them a very warm welcome. It was, he thought, very appropriate that the Iron and Steel Institute should hold its meetings in Glasgow, as the industries which it represented were of the greatest importance to the city and district; indeed, they always claimed that iron and steel had made their city great. When the hammers were busy and the furnaces were burning brightly then Glasgow was prosperous, but when the hammers were silent and the furnaces were dull the days were sad for Glasgow, and its splendid

mechanics and engineers suffered from bad times. He trusted that the meeting in Glasgow would be very successful and would do much to promote the welfare and progress of the industries the Institute represented.

Mr. JAMES MORTON (President of the Glasgow Chamber of Commerce) desired to convey to the members the warmest greetings and the heartiest welcome and good wishes, not only of the Chamber of Commerce in Glasgow, but of the whole trading and manufacturing community of the West of Scotland. They were deeply interested in the deliberations of the Institute. Their industries in the West of Scotland were for the most part founded upon iron and steel and coal, and they very fully realised that in the advancement of science and its more efficient application to the service of mankind lay the hope of the race, that there was no turning back in human progress, and that a higher standard of life and of comfort, less exacting labour and greater leisure, were everywhere demanded. They knew that if those demands could ever be gratified greater scientific efficiency and industrial technique alone could provide the means of gratification, and it was for the promotion of those things that the Institute existed.

Glasgow was not, he was afraid, such a gay city as those in which conferences were sometimes held. The citizens were, however, proud of their city and of their business enterprises. They lived in the centre of a very beautiful neighbourhood, and they ventured to hope, therefore, that the members would not only spend a very useful and instructive time in Glasgow, but an enjoyable time in seeing something of the surroundings also. If there were anything which the members of the Chamber of Commerce could do to promote that end, he need not say that they were very fully and freely at the disposal of the members.

Mr. JOHN CRAIG, C.B.E. (Chairman), said it now fell to his lot, as the spokesman of the West of Scotland Iron and Steel Institute and their colleagues in the industry, to bid the members a very cordial welcome to the West of Scotland, and he trusted that they would have in association with the members of the West of Scotland Iron and Steel Institute a very pleasant and instructive time.

They had come to a district which was rich in historical associations with the industry. It had been the birthplace of

many of the earliest and some of the greatest developments in the manufacture of iron and steel. He did not propose to dwell upon the history of the region, but he trusted that the members during their stay would see that the West of Scotland was still an active unit in the iron and steel industry, and that they were neither living in nor on the past. He hoped the papers submitted to the members at the meeting would prove to be full of useful information, and that the visits to the various works would likewise afford interesting examples of industry. As was natural in a district which had its beginnings centuries ago, moreover one which was among the first in the world to witness the development of steel manufacture, the members would see plants which in some cases were to be honoured for their age and for the lessons they had taught the industry, but he thought there might also be seen, in some of the works thrown open to them so willingly, installations laid out with a technical knowledge and skill which placed them in the front rank of enterprise of iron and steel production in the world.

He trusted that during their stay the members would likewise impart some knowledge which might help them to keep their place in the march forward in regard to the manufacture of iron and steel. It was well known that colossal difficulties existed in the industry. Those they were trying to forget, but unfortunately they were ever thrust upon them. He thought, however, they would be able to show that notwithstanding those difficulties—and they were great—they were still a unit which was endeavouring to take an honourable place in the metallurgical world.

In conclusion, he would say that no suggestion that the members of the West of Scotland Iron and Steel Institute had ever received was more cordially supported than that of the invitation to hold the meeting of the Iron and Steel Institute in the Glasgow district. He trusted, therefore, that the visit would be full of pleasure to the members, and on behalf of the West of Scotland Iron and Steel Institute he again welcomed them to Glasgow and to the various works which the proprietors had opened for their inspection.

The PRESIDENT (Mr. Frank W. Harbord, C.B.E.), in reply, said that on behalf of the Council, the members and himself, he

thanked the various speakers for the exceedingly gracious way in which they had been received, and for the cordial hospitality that had been extended to them. He believed the present was the fourth occasion on which the Institute had enjoyed the hospitality of Glasgow, and it was twenty-six years since the Institute had last had the privilege of holding a meeting in the great City of Glasgow. He was afraid that but few were present at this meeting who attended the meeting twenty-six years ago, though he himself had the good fortune to be one of them. He thought he was right in saying that the City of Glasgow traced its existence back to the sixth century. At any rate in the twelfth century it first had a Charter granted to it, and became a borough with a market and customs. Since then, by the industry and energy of the citizens, probably one of the greatest industrial centres in the world had been built up. Almost within the precincts of the city, and certainly within a very short distance from it, there were not only some of the greatest steelworks in the country, but some of the largest general engineering and structural engineering works, while the great shipbuilding industry on the Clyde was famous all over the world. The Institute was therefore meeting not only in a great steel centre, but in a great engineering centre which consumed probably more of the products made by the members than any other district in the country. Not only had the City of Glasgow taken a lead in commerce and industry, but it had always been in the van as regarded arts and science. The great University of Glasgow was evidence of that, together with the monuments which had been raised to the memory of distinguished sons of the city and the Art Gallery and the beautiful cathedral. The Royal Technical College in which the meeting was being held, which was affiliated with the University, showed how the citizens of Glasgow appreciated the importance of technical education as applied to metallurgical and applied science and general engineering. He again thanked the Lord Provost, the President of the Chamber of Commerce, and the President of the West of Scotland Iron and Steel Institute, for their great and cordial welcome. It was a signal honour to have been invited to be the guests of the great City of Glasgow, and they deeply appreciated the enthusiastic manner in which their various hosts had united to make the visit interesting, profitable, and entertaining.

This concluded the proceedings in the Examination Hall. The meeting then adjourned to the Societies' Room of the Royal Technical College, Mr. Frank W. Harbord, C.B.E. (President), presiding.

The PRESIDENT said it was his privilege to announce that Mr. Benjamin Talbot had been nominated for election as President for the following year.

BALLOT FOR ELECTION OF NEW MEMBERS

MESSRS. J. S. WALTON and A. L. CURTIS were appointed scrutineers of the ballot for the election of new members, and on completion of their scrutiny they announced that the following twenty-eight candidates for membership, and one candidate for associateship, had been duly elected.

MEMBERS.

NAME.	ADDRESS.	PROPOSERS.
Bamberger, Otto .	Keetmanstr. 10, Duisburg, Germany	V. B. Reichwald, Otto Blank, J. A. Smeeton.
Bevan, <i>Major</i> John M., B.A. (Cantab.)	Briton Ferry Steel Co., Ltd., Briton Ferry, Glamorganshire	T. Crosby, R. P. Bevan, A. O. Morgan.
Cape, Arthur Tregoning, A.R.S.M.	Central Alloy Steel Co., Massillon, Ohio, U.S.A.	F. W. Harbord, C.B.E., H. C. H. Carpenter, F.R.S., W. H. Merrett.
Cobden, Alfred Sydney .	72 Norfolk Road, Sheffield	F. C. A. H. Lantsberry, F. Smith, P. B. Brown.
Cook, Raymond W. .	The Wallace Barnes Co., Bristol, Conn., U.S.A.	G. P. Moore, F. P. Gilligan, A. H. d'Arcambal.
Darby, Henry Basil .	The Manor House, Harborne, Birmingham	H. B. Jacks, J. Craig, C.B.E., W. Simons.
Duby, André . .	60 Rue de la Victoire, Paris	Sir Robert Hadfield, Bt., A. Pourcel, F. W. Harbord, C.B.E.
Eagan, Thomas Evan, A.B., B.S. (Met.)	5150 Keyser Street, Germantown, Philadelphia, Pa., U.S.A.	F. B. Foley, H. Styri, T. Jobson.
Frisell, Sven . .	Holland House, Bury Street, London, E.C. 3	G. Dillner, A. Wahlberg, A. Grabe.
Galloway, John Galloway	8/10 Timber Bush, Leith	J. Dunnachie, W. W. McCosh, J. H. Andrew.
Gibbs, Charles William, A.M.Inst.C.E.	21 Avenue de la Toison d'Or, Brussels	F. W. Harbord, C.B.E., D. F. Campbell, E. F. Law.

NAME.	ADDRESS.	PROPOSERS.
Handforth, Joe Ridgway, M.Sc.	204 Meadvale Road, Ealing, W. 5	J. H. S. Dickenson, Cosmo Johns, G. E. Howarth.
Haque, Mohammad Abdul	Faraday House Electrical Engineering College, Faraday House, Southampton Row, London, W.C. 1	F. W. Harbord, C.B.E., E. F. Law, Vernon Harbord.
Herbert, Edward Geisler, B.Sc.	149 Barlow Moor Road, West Didsbury, Manchester	H. F. Massey, S. N. Brayshaw, E. R. Brayshaw.
Kadokawa, Isao, B.Sc.	Hyôgo-Kôjo, Kawasaki Dockyard Co., Kobe, Japan	H. Kikkawa, M. Otani, Y. Saio.
Matsumoto, Yosaburo .	Mitsubishi Ironworks, Kenjiho, Korea, Japan	T. Kawamura, K. Imaizumi, K. Tawara.
Orland, Joaquin . .	Alberto Aquilera 25, Madrid (8), Spain	J. M. Navarrete, S. A. Jackson, J. Vazquez.
Prest, Cyril Ernest .	24 Denison House, 296 Vauxhall Bridge Road, London, S.W. 1	W. A. Seaman, E. H. Saniter, L. Barlow-Massicks.
Reeder, David B. .	819 12th Street, Beaver Falls, Pa., U.S.A.	M. J. R. Morris, W. H. Schmid, R. S. Poister.
Rodes, Rafael Calvo .	Laboratorio Metalurgico, Aviacion Militar, Cuatro Vientos, Madrid	H. R. Pepper, S. A. Jackson, J. Vazquez.
Schwartz, H. J. . .	Armco International Corp., 64 Victoria Street, London, S.W. 1	W. Simons, F. W. Harbord, C.B.E., D. E. Roberts.
Steel, Gerald . . .	Wilsie Hall, near Doncaster	E. H. Saniter, L. Barlow-Massicks, W. A. Seaman.
Sunström, Henrik Rudolf	Gunnebo Bruk, Werkbäck, Sweden	K. J. Sunström, E. Wettergren, A. Grabe.
Taylor, Alfred J. T. .	Glen Lodge, St. George's Hill, Weybridge, Surrey	W. F. Cheesewright, A. P. Pehrson, D. M. Anderson.
Tottenham, Percy Marmaduke	Egyptian Government Office, 41 Tothill Street, London, S.W. 1	F. W. Harbord, C.B.E., D. F. Campbell, E. F. Law.
Trevorrow, Joseph Hicks Langford	Newbold House, Chesterfield	H. Brearley, A. P. Pehrson, F. S. Marsh.
White, William . . .	Butler, Pa., U.S.A.	B. Talbot, F. W. Harbord, C.B.E., Vernon Harbord.
Wyzalek, John F. .	294 Argyle Place, Arlington, N.J., U.S.A.	J. A. Mathews, H. J. Stagg, T. Jobson.
ASSOCIATE.		
Roberts, John . . .	48 Endcliffe Rise Road, Sheffield	C. H. Desch, T. F. Russell, W. G. Fearn-sides.

The SECRETARY submitted, in accordance with Rule 10, the following list of Vice-Presidents and Members of Council due to retire at the Annual Meeting in 1928. *Vice-Presidents*: Mr. George Hatton, C.B.E.; Mr. Alfred Hutchinson; and Mr. William R. Lysaght, C.B.E. *Members of Council*: Mr. E. H. Saniter; Mr. John Craig, C.B.E.; The Hon. R. D. Kitson, D.S.O., M.C.; Mr. Cyril E. Lloyd, M.P.; and Professor Cecil H. Desch, F.R.S.

PRESENTATION OF CARNEGIE GOLD MEDALS.

The PRESIDENT said that it now devolved upon him to perform the very pleasing duty of presenting Carnegie Gold Medals to three Carnegie Research Workers who had submitted valuable reports on research work carried out with the aid of grants from the Carnegie Research Fund. The award of the medal had been in abeyance since 1914, but the Council had now decided to reinstate the award, and in doing so to take into consideration all reports published during the last twelve years by research workers under thirty-five years of age at the time of making the original grant.

Three reports had been selected for the award of Gold Medals, the first of which was that by Mr. J. H. WHITELEY (Saltburn-by-the-Sea) on "The Eggertz Test for Combined Carbon in Steel." Mr. Whiteley was Chief Chemist of the South Durham Steel and Iron Company, and a number of papers and reports on original research work by him had been published by the Institute. He received a grant in 1916 for the particular investigation selected for the award of the medal. The report on his results was presented and published in 1917, and it formed an important contribution to the study of problems connected with the colour method devised by Eggertz for the rapid estimation of combined carbon in ordinary steels. The investigation aimed at throwing light on the relationship between the structure of the carbide in the steel and the result given by the test, and to discover whether the test would give some indication of the condition of the carbon in quenched steel.

(The President then presented the Carnegie Gold Medal to Mr. Whiteley.)

The PRESIDENT, continuing, said that he had to present the

second medal to Mr. FRANK BAINBRIDGE (Skinningrove) for his research on "The Effect of Fluorspar Additions on the Phosphates in Basic Slag," carried out in 1920. Mr. Bainbridge was a pupil of the late Dr. John E. Stead, under whom he studied for a period of five years. At the end of that time he joined the staff of the Skinningrove Iron Co., Ltd., as Steelworks Chemist. Later he was appointed to the position of Chief Chemist, which position he still holds under Messrs. Pease and Partners, Ltd. Mr. Bainbridge received grants from the Carnegie Fund to assist him in investigating the effect of fluorspar on the solubility of basic slag, the agricultural part of the experimental work being carried out in collaboration with Dr. E. J. Russell, working under the Board of Agriculture. The main results indicated that a basic slag made with the addition of fluorspar has considerable fertilising value, notwithstanding its low solubility. When large amounts of fluorspar were added, the manurial value of the slag was found to be not so good as that of a more soluble slag, and the phosphoric acid content of the grain and straw proved to be much less than when a citric acid soluble phosphoric slag was used. Mr. Bainbridge's report on his research work was published by the Institute in 1920.

(The President then presented the Carnegie Gold Medal to Mr. Bainbridge.)

Continuing, the PRESIDENT said the third medal was awarded to Mr. A. L. CURTIS (Chatteris, Camb.) for his research on "Steel Moulding Sands and their Behaviour under High Temperatures," published in 1925. Mr. Curtis received his training at Lincoln Technical School, and was a pupil for six years at the Engineering Works of Messrs. Robey & Co., Lincoln. Afterwards he took courses at the University of Pennsylvania, Philadelphia, U.S.A. He had specialised in the study of sands, refractories, and soils, and in 1922, 1923, and 1925 the Council made grants of money to him from the Carnegie Research Fund in aid of an extensive research on steel moulding sands and their behaviour under high temperatures. The investigation, which extended over several years, involved a study of natural argillaceous sands and of the sands used in current practice for steel facing mixtures. He demonstrated the great variations found in such sands, and that these variations could be more quickly proved by refractory and

washing tests than by chemical analysis. A very exhaustive series of such tests was made, the results of which were fully described and illustrated in the comprehensive report presented by him and published by the Institute in 1925.

(The President then presented the Carnegie Gold Medal to Mr. Curtis.)

The following papers were read and discussed :

- T. W. ROBINSON : "The Economic and Social Development of the American Iron and Steel Industry."
- W. ROSENHAIN and D. HANSON : "The Behaviour of Mild Steel under Prolonged Stress at 300° C."
- D. HANSON : "The Constitution of Silicon-Carbon-Iron Alloys, and a New Theory of the Cast Irons."
- A. B. EVEREST, T. H. TURNER, and D. HANSON : "The Influence of Nickel and Silicon on an Iron-Carbon Alloy."
- E. H. LEWIS : "The Use of Silica Gel as a Medium for Drying Blast."
- F. WÜST : "A Contribution to the Theory of the Blast-Furnace Process."
- C. S. GILL : "The Effect of Varying Ash in the Coke on Blast-Furnace Working."
- D. F. CAMPBELL : "High-Frequency Induction Melting."
- H. A. DICKIE : "Magnetic and other Changes concerned in the Temper-Brittleness of Nickel-Chromium Steels."
- C. A. EDWARDS and K. KUWADA : "The Influence of Cold-Rolling and Subsequent Annealing on the Hardness of Mild Steel."
- E. G. HERBERT : "The Work-Hardening of Steel by Abrasion."
- J. H. WHITELEY : "The Solution of Carbon in α -Iron and its Precipitation."

The following papers were taken as read :

- K. HONDA and K. TAKAHASI : "On the Quantitative Measurement of the Cutting Power of Cutlery."
- T. MATSUSHITA and K. NAGASAWA : "The Mechanism of Tempering of Steels."
- J. H. SMITH and F. V. WARNOCK : "A Testing Machine for Repeated Impact, and a Preliminary Investigation on the Effects of Repeated Impact on Lowmoor Iron."

VOTES OF THANKS.

The PRESIDENT said the very pleasant duty now devolved upon him of proposing a cordial vote of thanks to all those who had taken a part in making the meeting at Glasgow such a great success. The members had during the past three days enjoyed the unbounded hospitality of the great City of Glasgow, and he was sure they would pass with acclamation the resolution which he was about to read. He had much pleasure in proposing :

“ That a very hearty vote of thanks be accorded :

“ (1) To the Lord Provost, the Lady Provost, the Magistrates and Corporation of the City of Glasgow, for their warm welcome and hospitable reception of the members and their ladies in their magnificent City Chambers on the first evening of the meeting.

“ (2) To Mr. John Craig, President of the West of Scotland Iron and Steel Institute, to the Council of that Institute—out of whose members the Executive Committee had been formed—and to Mr. D. A. MacCallum, the Hon. Secretary, for all the arrangements so excellently planned and admirably carried out for the entertainment, comfort, and convenience of the members. Cordial thanks were also due to the Lady Provost (Mrs. David Mason), Mrs. R. Crichton, and all the members of the Ladies’ Reception Committee, for their great kindness in devoting themselves to the ladies during the meeting.

“ (3) To Mr. James Morton and the Councillors of the Glasgow Chamber of Commerce, for their warm welcome and most hospitable entertainment during the days of the meeting.

“ (4) To the Chairmen and Directors of those firms who had so generously thrown open their works to the visiting members, and had permitted the inspection of their plants and processes.

“ (5) To the Director and Board of Governors of the Royal Technical College, for their great kindness in placing the rooms of the College at the disposal of the Institute for the purposes of the meeting for the reading and discussion of the papers.

“ (6) To the Chairmen and Committees of the following Clubs, who had courteously extended the facilities of their premises to the visiting members :—The Conservative Club, the Constitutional Club, the Liberal Club, the Automobile Club, the City Business Club, and the Royal Exchange.”

The resolution was carried with acclamation.

Professor C. H. DESCH, F.R.S., said that he was sure that before the proceedings concluded the members would desire to express their thanks to the President for the very admirable and business-

like way in which he had conducted the meeting and the functions during the meeting. It was always a difficult task for the President to undertake. During the few days of the meeting the President was exceedingly hard worked, but Mr. Harbord had fulfilled his duties admirably, and he was sure the members were greatly indebted to him for what he had done. He asked the members to accord a very hearty vote of thanks to Mr. Harbord for his conduct in the chair.

The resolution was carried with acclamation.

The PRESIDENT expressed his thanks to the members for their very kind appreciation of the small services he had been able to render. He had tried to do his best, and that was all he could say.

The meeting then terminated.

THE ECONOMIC AND SOCIAL DEVELOPMENT OF THE AMERICAN IRON AND STEEL INDUSTRY.¹

BY THEODORE W. ROBINSON, VICE-PRESIDENT,
ILLINOIS STEEL COMPANY, CHICAGO.

THE social and political character of any nation is largely dependent upon the extent of its economic welfare, and the prosperity of all classes of its people is contingent upon the prosperity of its basic industries.

Because iron and steel directly or indirectly enter into every form of human activity and touch the life of every civilised human being, the conditions surrounding their manufacture mirror to a marked degree those of business in general. This is particularly true in the United States, which has enjoyed unusual industrial activity during the last few years. A description, therefore, of some of the more important changes that have affected the manufacture of iron and steel may well serve not only as a text of the progress of the industry itself, but as a means of illuminating some of the reasons for American prosperity as a whole. If this contribution helps toward a better understanding of an economic and social situation which during the last few years has been a source of widespread interest and investigation, its purpose will have been achieved.

Because of its subtlety current change needs time and distance for a proper perspective, and for the better comparison of the development of the United States in recent years a chronological base line has been established at the ushering in of the twentieth century. While this discussion is thus specifically concerned with the development of the last twenty-five years, the prelude of an earlier background may throw into stronger relief some of the conditions and forces that are in play to-day.

As late as 1860 manufacturing in the United States was chiefly confined to comparatively small units located in the communities

¹ Received August 2, 1927.

that fringed the Atlantic seaboard. Transportation was slow and costly, and distribution was largely for local consumption. Industrial ownership lay in the individual, partnership, or small corporation, and there was close contact between men and management. Wages and output were low, luxuries few and far between, and standards of living were relatively simple.

Then came the epoch-making pneumatic process for making steel. It was the beginning of the industrial revolution which has made America the great workshop that it is to-day. The iron and steel industry was quick to grasp the possibilities of the new process, and steel plants began to spring up here and there throughout the country. By the Bessemer rail the Far West was opened, and the North and South were tied together. For thirty years unparalleled expansion followed the rapid development in railway construction, and men swarmed to American shores in response to the call for labour.

By 1880 manufacture was rapidly forging to the front. Individual ownership of the shop was giving way to the small corporation, and the small corporation to larger aggregations of capital. The former employer was becoming the employé, and there was less personal touch between owners and workmen.

With better and more extensive transport facilities industry became more highly centralised, and rural life was replaced more and more by urban life. The relative crowding of industrial centres helped to accentuate the change from former standards of living, and the transition was not always conducive to contentment and well-being. Factory conditions were crude and too often unsanitary, and the physical hazard of industry rapidly grew through the increased installation of power and machinery.

A class consciousness developed to an extent unknown before. The country was becoming richer, and with increased wealth capital was prone to be more intolerant and labour more independent, while both gave less heed than formerly to the power of public opinion ; but in spite of these throes of a new industrial birth the country continued to expand.

In reviewing this period it is clear that the underlying reason for the remarkable progress made in the twenty-five years following the close of the Civil War in 1865 was the introduction of the Bessemer process. No single industrial invention ever had such

a vital and far-reaching effect on the commercial and social destiny of any nation as this new steel-making process had upon the United States. The first Bessemer ingot made in the New World was produced at an experimental plant at Wyandotte, Michigan, in 1864, but steel did not begin to be an important factor in the replacement of iron till ten or fifteen years later.

When the Illinois Steel Company was organised in 1889, with an authorised capital of \$25,000,000, by the combining of three important steel-producing companies in the Chicago district, it was properly heralded as an outstanding feat of corporate development. It represented at that time the most forward step in individual control of pig iron and steel-producing plants, but even in this case the company lacked complete operation, and had largely to depend upon outside parties for their ore and coal supply. As with other large steel producers in that period, the finished product chiefly consisted of rails, while the blooms and billets, which mainly made up the balance, were but the raw material for finishing mills belonging to other interests.

The following ten years from 1890 to 1900 were momentous in their import to the country, and were fraught with consequences that were fundamental in their influences upon the present life of the American nation. This period recorded the true beginning of big business, and iron and steel again played the most important rôle. The first seven years of the decade beginning with 1890 were lean and hungry. The necessity of rigid economy was emphasised by the severe industrial depression that existed. Liquidation became general and drastic, and by the time the pendulum swung toward brighter things the country was ripe for the saving and profit that lay in combination.

In 1898 the Federal Steel Company was formed with an authorised capital of \$200,000,000. This brought under one management ore, coke, iron, steel, and transportation, to an extent only approximated by the Carnegie Steel Company. During this period most of the finishing mills throughout the country were brought together into large units, and they controlled in their separate entities the wire, tube, tinplate, hoop, and sheet steel products of the country.

Such consolidations in iron and steel were largely typical of the change that was taking place throughout the manufacturing

industry as a whole. It was a time of feverish activity. Promotion was rife, business ethics were low as compared with present standards, and as a result of public mistrust there was a marked change in Federal and State legislation from one of permission to one of restraint.

The Dawn of the Twentieth Century.—The twentieth century opened auspiciously for the United States amidst long-deferred prosperity. The rapid progress made in the period just reviewed was founded upon new processes and new methods, distinctly technical in their character, which followed the introduction of the manufacture of steel.

The progress during the last twenty-five years, however, has been more essentially the result of social and economic change. Its history is a story of a nation adopting and assimilating the principles of big business ; of the mobilisation of its capital and credit through the Federal Reserve system ; of increasing its industrial output through co-operation, integration, and mechanical energy ; of developing modern management as an entity separate from owner and worker, and of more equitably dividing among its people the fruits of industry through better opportunity and higher wages. In short, the story of the first quarter of the twentieth century is one of a nation commanding for its people the highest standards of living ever achieved by any nation by the scientific study and application of man and machine.

During the last twenty-five years the income of the United States has nearly doubled, while its population, though largely increased, has grown in a lesser ratio. The significance of these changes lies not so much in the increase in the nation's production of wealth as a whole, as in the surplus purchasing power that has sprung from the increased output of the individual worker. A large family may produce in the aggregate much more wealth than a small one, but if the large family accumulates no surplus, a small family with greater individual productivity and with the same proportionate cost of living may grow rich while the large one remains poor. A vital factor in the development of the twentieth century, and one which has been especially emphasised in the United States since 1914, is the multiplication of individual effort rather than the effort of multiplied individuals.

The United States during the past few years has been experi-

encing the unprecedented economic condition of continuously falling commodity prices, high wages, and continued prosperity. Any intelligent attempt to explain this anomaly must recognise certain elementary economic principles.

It is clear that wealth cannot be divided until it is produced, and obviously the more there is produced by each workman the more there is to be divided. Wages and dividends are primarily matters of wealth's distribution—not of its production. High wages mean high consumption. The larger the output of the individual workman, the greater is the tendency to lower costs and the greater the possibilities of return in wages and in dividends. Present easy money and low inventory are factors that influence but do not answer the question before us. High wages as a matter of distribution instead of production are an effect rather than a cause, and raw material, of which our forefathers had much more than we, is but of potential value until converted.

These are elements that enter into a complex problem, but do not explain it. Neither would increased production if accomplished merely by a proportional increase in the number of workers. The true answer to this economic paradox of combined high wages and lowering prices of goods, and the underlying primary cause of the late industrial progress of the United States, lies in the increased and unrivalled output of the individual American workman, and the large accumulation of wealth that has resulted from it.

The extent of this wealth is indicated by figures recently compiled by the National Industrial Conference Board from Washington statistics. These show that the value of the yearly product of the average workman in all the manufacturing industry of the United States rose from a *per capita* production value of \$3214 in 1904 to \$4682 in 1925, as measured by the common purchasing power of the 1914 dollar. This represents an increase of 45·7 per cent. in the manufacturing output of the average individual workman, which if applied to the total volume of manufactured product signifies that the increase of wealth in 1925, due solely to the increase in *per capita* production, amounted to \$12,304,000,000 more than it would have been had the output of the average worker been no greater than it was in 1904 ; in other words, one-third of all the wealth that was produced that year

1927—ii. c

from the nation's manufacturing industry was directly due to the increased productivity of the average individual workman.

How profound an influence such vast sums have on the whole economic structure of the country is perhaps better visualised when it is realised that twelve and three-tenths billions of dollars, on the basis of present individual production, is equivalent to the output of 2,628,000 men—a number equal to nearly one-third of the entire working force of the United States engaged in the manufacturing industry. That the productive efforts of such a vast army of workers can be laid aside by machinery and management and rendered available for other additional work without an average increase in the country's non-employment is a striking commentary on the stimulating and absorbing effect of increased individual production.

The average output of the individual workman in the United States is to-day greater than ever before, and is much larger than that of any other nation. Canada comes next to the United States in individual productivity, and America finds its antithesis in the archaic industrialism of China.

An explanation of the increased efficiency attained by the manufacturing industry of the United States is found in the development of its iron and steel production. Of all basic industries the manufacture of iron and steel ranks first in fundamental importance and second in the amount of wages paid.

Production of Iron and Steel.—In 1901 the United States with its output, in round numbers, of 13,500,000 tons of ingots and castings, produced 44 per cent. of the world's steel. This by 1926 had expanded to more than 51 per cent. of the world's total, with its production of over 48,000,000 tons of steel. Whereas twenty-five years ago the steel ingots made in the United States consisted of more than 66 per cent. acid Bessemer, nearly 84 per cent. of the steel now produced is of basic open-hearth. This, in brief, tells the nation's accomplishment for the first quarter of the century, and records the large replacement of the Bessemer converter by the open-hearth furnace, a change superinduced by the changing character of the country's ore reserve.

The causes for this impressive growth, while clearly complex, are largely predicated upon economic and social change rather than upon any pronounced technical difference in method of

manufacture. In principle, the blast-furnace, open-hearth, Bessemer converter, and rolling-mill are still the unchanged agents of reduction and conversion, and there has been but little progress made in the fundamental metallurgy of iron and steel during the twentieth century. Momentous advances in technique and the refinement in operation have resulted in an increase of output which can only be partially attributed to a multiplication of plants.

The production records of the past twenty-five years at the South Chicago Works of the Illinois Steel Company furnish a concrete illustration of the effect of such advances. These works represented in 1901, as they do now, the best modern practice. The average daily output of each of the South Chicago blast-furnaces increased from 318 tons in 1901 to 679 tons in 1926. During this period the acid Bessemer department increased its production from 70,000 tons to 100,000 tons per month, and the basic open-hearth furnaces increased from an average output per furnace of 586 tons per week to 1379 tons per week. The South Chicago rail mill had an average capacity of 60,000 tons per month in 1901, while the Gary rail mill, by which it has been replaced in the rolling of rails, has a capacity of 100,000 tons per month. These figures reasonably illustrate the unit advance in physical production which has taken place in the iron and steel industry in the United States.

A still more important development in American practice is the increased *per capita* output of the average iron and steel workman. This is strikingly illustrated by the following South Chicago records :

Illinois Steel Company (South Works).

Tons produced per Man-Hour.

	1902.	1926.	Increased Percentage.
Ore unloading	2.087	16.835	706.7
Blast-furnaces	0.185	0.698	277.3
Bessemer ingots	0.421	0.841	99.8
All open-hearth ingots	0.252	0.418	66.0
Rail mill (South Works, 1902) }	0.189	0.416	120.1
„ „ (Gary Works, 1926) }			

This table shows that the average man in a modern iron and steel plant is producing from $1\frac{1}{2}$ to eight times as much as he did

twenty-five years ago. If translated into yearly volume, these figures indicate that at South Chicago the average workman has increased his ore-handling capacity since 1902 from 6000 to 48,000 tons ; his pig iron output from 675 to 2405 tons ; his Bessemer ingot production from 1761 to 3730 tons ; his open-hearth ingot production from 1049 to 1842 tons ; and his rolling capacity from 603 to 1240 tons of rails.

That this accomplishment is fairly typical of the changes that have taken place in like branches of the industry for the country as a whole is supported by data lately published by the United States Department of Labour, which shows an average increase in worker productivity upon a man-hour basis of 165 per cent. from 1899 to 1926 for crude iron and steel products.

These results are impressive when it is recalled that they are based upon actual continuous records running over a quarter of a century in a plant which in 1901 represented the latest development in equipment, organisation, and method, and one that during the intervening years has kept abreast of current change.

Such a transformation is essentially due to the enlargement of units, refinement of design, and the installation of labour-conserving appliances rather than to fundamental changes in process. Behind these, however, is the large addition of mechanical energy by which these improvements have been made possible, and at the back of all lies enormous investment and co-operation of men and management.

Power Installation.—The manufacturing productivity of any nation can be roughly measured by the amount of its mechanical energy, and the marked growth of power application in the United States has made possible its expansion and prosperity. From 1899 to 1925 the country's primary horse-power more than trebled, and as a result of this increase there is now $4\frac{1}{4}$ horse-power at the service of every manufacturing wage-earner.

On the conventional assumption that one horse-power is equal to the unassisted physical effort of ten men, the average capacity of the individual worker in the United States is more than forty times what it would be if unaided by mechanical energy.

The manufacture of iron and steel has more than kept pace in power installation with the progress made in general industry. During the last twenty-five years its use of power has increased

nearly fourfold, and to each of its workmen there is now given the energy of over sixteen horse-power.

The extent to which power usage has been amplified and the electrification of plant increased is strikingly exemplified by the Gary Works of the Illinois Steel Company. A short generation ago the reciprocating steam-engine was the principal prime mover in both primary and secondary units. At Gary the production and utilisation of power is dependent upon the blast-furnace gas-engine, steam-turbine, electric generator, and motor. Here 11,716 men were able in 1926 to turn out more than $2\frac{1}{2}$ million tons of finished product, because behind each of them was the electrical energy of nearly twenty horse-power.

Wages and their Relation to Living Cost.—It is but natural to ask whether or not the increase in worker productivity, in which power usage is such an important factor, has been followed by an increase in "real wages." Wages and earnings in the Chicago district may be considered as typical of those existing elsewhere in the iron and steel industry of the country. In 1901 the daily wage was based on fifteen cents per hour, and the average yearly earnings of all employes of the South Chicago Works for that year was \$825. By 1926 the hourly rate had risen to forty-four cents, and the average yearly earnings to \$1870, an increase of 127 per cent., or more than double the amount of earnings received before. With this increase in earnings went also a reduction of nearly 18 per cent. in the hours the men were required to work. Prior to 1922 the iron and steel industry had been operated almost universally on the basis of twelve hours for continuous operations, and ten hours for non-continuous operations. In that year the present eight- and ten-hour day working schedule was adopted, and several years earlier the seven-day week had been replaced by the six-day week.

In the first decade of the century there was no striking change in the basic cost of living or in the wage scales. By 1914, however, there had become pronounced that vicious circle of high commodity prices, high cost of living, and high wages which a few years before had begun to evidence itself. War conditions aggravated the situation, and commodities, living costs, and wages rapidly pursued one another upward in an ever-expanding sequence until the deflation of 1921. The social and economic consequences to

the wage-earner and to industry are told by the following result of governmental investigation. Earnings in twenty-three representative industries increased 115 per cent. between 1914 and 1925. Living costs of workers' families rose 68 per cent., and the hours of labour decreased more than 6 per cent.

These figures indicate that wages in the manufacturing industry have more than kept pace with the increase in commodity prices. The surplus earning power thus represented well explains the present wide consumption of luxuries and the high standard of living that now exists.

Prices and Investment.—Granting that the economic change during the last twenty-five years has been distinctly beneficial to the wage-earner, what has been the contemporaneous effect upon the consuming public and investor ?

If we take the price relation that existed between the composite steel price and the wholesale price of commodities in 1913 as a base, we find that whereas in 1901 the price of steel was relatively 52 per cent. higher than that of commodities, it was in 1926 3 per cent. lower. The composite price of steel is now practically 27 per cent. higher than in 1901, while the wholesale price of commodities has increased 99 per cent. Due to efficient management, the spending of many millions in power and machinery, and the co-operation of labour, the consumer, relatively speaking, is buying steel now cheaper than he did twenty-five years ago.

With the investor of to-day it is a somewhat different story, and this is especially true if there be borne in mind the difference in the amount of money represented by capitalisation upon which dividends are paid, and the much larger sum that is represented by the balance-sheet, and upon which earnings are dependable.

While there are from the Government no exact figures of the amount of money that is now invested in the iron and steel industry, the published balance-sheets of steel companies representing over 85 per cent. of the country's ingot capacity show a capitalisation of approximately $4\frac{1}{2}$ billion dollars. According to these reports, earnings for the years 1925 and 1926 are respectively 5.61 and 6.70 per cent. on the capital invested. It thus appears that while the wage-earner, the consumer, and the public in general have been very distinctly benefited, capital has not fared so well.

Increase in Steel Capacity.—Due to the exigencies and stimulation of the war, the ingot capacity of the United States increased slightly over 15 million tons for the six years 1915 to 1920 inclusive, or at the rate of approximately $2\frac{1}{2}$ million tons per year.

The end of the war left the country with excess plant development, and for six years subsequent to 1920 the total ingot capacity increased less than $3\frac{1}{2}$ million tons, or at the approximate rate of half a million tons per year. The theoretical steel ingot capacity of the nation is to-day, in round numbers, 58 million tons. While during the war no expense was spared to enlarge the country's steel capacity, investment during the last six years has been made with special reference to the reduction of costs, diversification of product, and the betterment of quality instead of increased production.

This explains why the installation of power and labour-saving machinery has been of late so strongly emphasised, and why there has been such heavy scrapping of inefficient and obsolete machinery and plant. Irrespective of its physical condition or its length of service, it is not good business to continue to use machinery if a better design will pay a fair return on its investment by reducing costs. The American practice is drastic in this regard, and it is only by such a progressive policy that any concern or any nation can hope to keep abreast of the times and successfully maintain its position.

But given the vision and courage to adopt such a policy, whence comes the capital with which to finance such undertakings? It may be trite to recall that capital, practically speaking, is but earnings saved, but it is perhaps not so obvious that the amount of saving largely depends upon the surplus output of the individual. Because this surplus has been gradually expanding for many years through reproductive effort and reproductive investment, not only has wealth grown but its distribution is wider than ever before.

The nation's savings deposits of over $24\frac{1}{2}$ billion dollars, with its $46\frac{3}{4}$ million depositors, is an index of the extent to which capital has been distributed, and the long lists of small stockholders in industrial corporations illustrate the rapidly growing character of its investment. The aggregate wealth of the United States no

longer lies in the excessively rich, but in the small property owner whose name is legion, and more and more does management represent and stand between him and concentrated ownership.

Management.—Just as the exigencies of expanding business fifty years ago resulted in the small corporation taking the place of individual ownership and control, so their resulting economies brought into existence the larger corporations of to-day. In the last two decades of the nineteenth century there was not always a proper appreciation of the difference in power and responsibility between large and small aggregations of capital. Management was then apt to measure responsibility and success by the profits it made rather than by the methods it employed. The rights of the public, the competitor, and employé were oft-times neglected ; monopoly was not always discountenanced ; labour was sometimes exploited ; prices were apt to fluctuate from exorbitant heights in good times to ruinously low figures in bad times ; competition was frequently destructive, and business ethics too often failed to square with the golden rule.

Such principles and methods of doing business fell into disrepute years ago. Management learned that the difference between monopoly and unreasoning competition is the difference between ephemeral success to the few and industrial suicide by the many, that the exorbitant profits of a peak demand were offset by the losses of succeeding reaction, and that stability in price helps stability in operation.

To-day modern management stands not as the representative of capital alone, but as an entity representing the interests of the public, the stockholder, and the employé. For the development of this sense of plural trusteeship and the creation of the new spirit of co-operation that now animates all well-managed American concerns, the management of the United States Steel Corporation is in no small measure responsible.

The United States Steel Corporation commenced business on April 1, 1901, with a capital structure of nearly $1\frac{1}{2}$ billion dollars. It represented a merger of ten large companies, each prominent in its own field. It was a consolidation of consolidations, most daring in its conception and destined to be monumental in its achievement. Its initial capacity in steel ingots and castings was $9\frac{1}{2}$ million tons, which comprised 65 per cent. of the country's total

output. To-day it represents but 45 per cent. of the nation's tonnage with its production of 23 million tons.

At the time of its organisation the failure of the enterprise was freely prophesied because of its colossal size. The public was suspicious of its monopolistic potentiality. Organised labour dreaded its power, and rivals feared possible unfair competition. During its existence it has twice been seriously attacked by organised labour, and for years it was in the courts because of the Government suit brought for its dissolution.

In spite of dire prophecy and unjust attack the corporation, after more than a quarter of a century of constructive effort, not only stands to-day absolved by the Government and the people of unfair practice, but is recognised throughout industry as an exemplar of efficiency and high business standards.

Since the beginning of the United States Steel Corporation Judge E. H. Gary¹ has guided its policies. To him is largely due that publicity in corporate affairs which principally found its birth in the innovation of regular and detailed statements of the Corporation's activities. To the public the Corporation's policy has meant reasonable prices and knowledge of the Corporation's results; to its competitors, co-operation and a stabilising influence; to its employes a more generous return than ever before paid by the industry; and to its stockholders a fair return on their investment.

In management as in other departments of American industry the job seeks the man, and character and ability are the determining factors. Perhaps nowhere is the success of this dominant policy more strikingly illustrated than in the leaders of America's two largest corporations in the steel industry. The character and accomplishment of Elbert H. Gary¹ and James A. Farrell of the United States Steel Corporation, and Charles M. Schwab and Eugene G. Grace of the Bethlehem Steel Company, chief executives and presidents respectively of their corporations, need no elaboration here. Their prestige and resource is distinctly an heritage of ability and hard work, and their history symbolises to a marked degree American opportunity and American accomplishment.

Labour.—Because of the large increase in the number of small investors the line of demarcation between so-called labour and

¹ Judge Gary's death on August 15, 1927, occurred after the above was written.

capital is rapidly lessening. There is a better appreciation to-day that the nation's capital is principally the savings of labour's thrift and is largely owned by labour itself. With the dissemination of this truth has also gone a better realisation that in American industry the labour of the office and counting-room is in the same economic category as the labour of the mill or field, and that the officials of management are just as truly employ  s of the corporation which hires them as the men working under their direction.

The composite American workman is of a high order of intelligence, peculiarly free from traditional bias and restraint, and welcomes as a rule mechanical assistance for the increasing of his output because of its greater attendant earnings. He is especially jealous of his right to freedom of action, is quick to resent unjust treatment, and does not hesitate to change the character or place of his employment if dissatisfied or if better opportunity presents. He resents political and organised domination, and prefers his own negotiations to bargaining by representatives.

That these statements reasonably reflect the general character of the largely predominating mass of skilled and unskilled labour in the United States to-day is demonstrated by the fact that attempted political dictation by organised labour even in their own ranks has been a failure, and that the United States is essentially an open-shop country. Of the 117,000,000 of its inhabitants about 44,000,000 are "gainfully" employed, and of these about 8,500,000 are found in the manufacturing industry. Organised labour has in its enrolment something less than 4,000,000 workers, and these are principally found in the mining, transport, building, and textile industries.

Formerly when short-sighted management oft-times led to the oppression of the worker, and when co-operation between employer and employ   was more stressed by its breach than by its observance, organisation of labour grew rapidly, because of its protective appeal to the individual. To-day, however, a better understanding of common aims and a clearer knowledge that even armed neutrality is unprofitable, has resulted in an appreciable lessening of interest on the part of the worker in labour organisations, as is indicated by a reduction in the membership of the American Federation of Labour from 4,078,740 in 1920 to 2,803,966 in 1926.

The iron and steel industry of the United States is operated on an open-shop basis. Employment is not concerned with nationality, politics, religion, or union affiliation ; and plant representation, negotiation as to wages, and methods of work are distinctly between the management and the men, singly or collectively, and not through outside agents.

An exception to this general rule is found in a few small mills where the Amalgamated Association of Iron and Steel Workers is still recognised. That their influence is small is indicated by the fact that while the iron and steel industry employs about 400,000 men, the Amalgamated Association's enrolment has fallen from a membership of 14,035 in 1900 to 11,174 in 1926.

Some of the American labour unions have maintained their position through conservative leadership and the rejection of radicalism. More, however, have lost ground by attempting militantly to force domination on peaceful industry and by insisting on wages, hours, and rules that were unfair to the public because out of harmony with economic principles and existing conditions.

It is one thing for labour or for management to use its might to right a wrong. It is another thing to disrupt a community or a nation for selfish aggrandisement, and American public opinion has thus far refused to sanction special privilege to either labour, management, or capital.

As a result of this attitude both management and labour have found that fair dealing is remunerative as well as ethical ; and that co-operation is more productive than oppression. That there has been of late years much better co-operation on the part of the vast majority of the labour body is by no means solely due to the higher wages that they have received. Management early in the century began more practically to recognise their obligations to the human side of industry. It found that the minimisation of occupational hazard, sanitary surroundings, hospitals, better housing, and other welfare work which promoted the health and happiness of the worker and his family, was not only humane, but paid by the goodwill and the co-operative spirit that it inculcated. In the development and application of this new science of human engineering the iron and steel industry, inspired by the example of the United States Steel Corporation, has taken a most prominent part.

In 1906 the United States Steel Corporation inaugurated a campaign of safety, sanitation, and welfare which has ever since been vigorously pursued. Tonnage and costs became no longer the *sine qua non* of achievement, and the safety and welfare of the worker is a vital consideration in mill operations.

Accident prevention has naturally been most prominently stressed. The safeguarding of machinery starts with the drafting board in all construction, and is diligently pursued thereafter as experience permits. Education and organisation of men into safety committees plays an important part, and that expense is not allowed to interfere with the desired object is indicated by the expenditure by the United States Steel Corporation last year of $1\frac{3}{4}$ million dollars in safety work.

As a result of such intensified effort extraordinary reduction in the accident rate has been achieved. Among the quarter of a million men employed by the United States Steel Corporation in 1926 the rate of disabling accidents was 3.26 per cent. as compared with 20.57 per cent. in 1912, or a reduction of 84.15 per cent. of the former rate. That means that in the company 365,277 men have been saved from disabling injuries since 1912, as measured by the sum of the reduction in accidents each year.

In addition to the payment of liberal wages various corporations seek to improve the financial condition of their employes by affording them the privilege of stock subscription on advantageous terms. In the United States Steel Corporation, in illustration, there were 47,647 employes registered as stockholders as on December 31, 1925, who held 665,801 shares of the Corporation's preferred and common stock, with an aggregate value of over 100 million dollars. Like the Corporation's safety and other welfare activities, this method of encouraging a partnership relation is absolutely divorced from any paternalistic method or condition, to which both men and management rightfully object.

Consumption and Markets.—At the beginning of the century the United States, with a population of 76,000,000 people, produced $9\frac{1}{2}$ million tons of finished steel, while in 1926, with a population of 117,000,000, this output had risen to $35\frac{1}{2}$ million tons. In other words, each inhabitant as an average used 739 lb. of finished steel in 1926 as compared with 279 lb. in 1900, or over $2\frac{1}{2}$ times more now than formerly. This expansion is essen-

tially due to increased domestic demand, and has been but little influenced by the small percentage of growth in the country's foreign trade. The following statistics show how small this change has been. The iron and steel imports and exports of the United States, in round numbers, were respectively 200,000 tons and 1,000,000 tons in 1900 as compared with imports of 1,000,000 tons and exports of 2,000,000 tons in 1926.

The increasing ramifications of steel's new uses are continually making for widening markets. With greater diversification of product has come an insistent demand for quality, so that to-day trade requirements are infinitely more severe than in former years. The comparatively rapid growth of alloy steels and the increasing call for electrical refining is a result of this demand, and such special steels are an important and growing factor in the economic progress of the country. The change in the character of the demand is illustrated by the item of rails. At the beginning of the century the production of rails absorbed 25 per cent. of the country's entire steel output. Last year, although the rail tonnage was half again as large as it was twenty-five years ago, it represented only 9 per cent. of the country's steel production.

In the new demand for steel the most important development is the expansion of the automotive industry, which last year took 15 per cent. of the nation's output.

In the development of this industry the accomplishment of Henry Ford is outstanding. To his genius, courage, and vision we must pay high tribute when analysing the effect of high production and the increased *per capita* production that has followed his methods. To his doors has come the world to study the specialisation of men and machines, and his practice and high wages have been made prosperity's text by various international expounders of economic and social conditions. But while industry owes much to Mr. Ford, his methods and his results may easily lead to false conclusions if superficially studied. Thanks to his foresight and inventive genius, he produced a car which in its sturdiness and its low price so far outclassed his competitors as to amount temporarily to a monopoly. With an almost insatiable public demand, his profits, though legitimately made, were so large as to put his enterprise outside the pale of ordinary competitive conditions.

It is as a monopoly, not as a competitive industry, that

Mr. Ford's past achievement must be studied if proper deductions are to be drawn. The present intensive competition by powerful interests, in low-priced models, promises to emphasise this fact.

Between the manufacturers of steel in the United States there is free exchange of ideas and information in respect to equipment and practice, and former secrecy has given way to a courteous welcome to both foreign and domestic competitors. In the matter of sales, however, while information concerning prices may be legally exchanged, anything in the way of price agreement or restraint of trade is outside the law. Although industrial combination carries with it the possibility of service to the community by saving in operation and saving in distribution, it may also carry with it the possibility of unreasonable prices. That the public in the United States feared the possible monopolistic power of the industrial merger more than it appreciated its constructive force is evidenced by the Sherman anti-trust law and the subsequent anti-trust legislation that has been enacted. The difference between governmental encouragement of the cartel in Europe, and the discouragement of industrial combinations in the United States is, therefore, a difference in the public state of mind. That the United States laws against trade agreement and in favour of unrestricted competition are economically sound is subject to grave question. That uncontrolled licence to combine would be in the long run more economically sound is likewise open to doubt. Possibly a happy medium could be found in permissive regulation. In any event, President Coolidge's dictum of more business in government and less government in business rings true in the light of general experience.

SUMMARY.

The economic progress or retrogression of any nation depends upon the expansion or curtailment of the individual production of its workers, and the secret of America's well-being lies in its unrivalled *per capita* output.

At the back of all accomplishment, however, is human effort, and the installation of power and the wealth of material resource will be but abortive aids unless utilised and directed by the hand of able and willing labour.

The character of any people depends upon their education and environment, and their material welfare can only be assured if founded upon sound economic methods. The irrevocable law of supply and demand is nothing but human nature reduced to a formula, and composite human nature is unchangeable in its primary instincts in spite of civilisation's veneer.

Consumption is vitally affected by costs of production, but for management to lower costs by reducing wages if they are reasonable is just as short-sighted as for labour to try to improve its condition by restricting its output. Both, if continued, must inevitably lead to lower standards of living.

High wages and high dividends can only come from high production, and high production will be better assured if labour is not only paid to produce but also is paid by what they produce. Tonnage rates, piece-work, and bonuses for favourable performance spell high earnings when justly formulated, and American production owes much to this enlightened method of labour remuneration.

Prosperity to continue must be based upon a thriving public, contented labour, and adequately remunerated capital. If any one of this essential trinity becomes unbalanced the wheels of industry will slow down and prosperity disappear.

As a prophet may not be without honour, save in his own country, the author ventures the prediction that as war has given way to peace, so will ignorance give way to economic enlightenment, and that in the new spirit of industrial co-operation there will be found both greater prosperity and a better understanding between the nations of the earth.

DISCUSSION.

Mr. BENJAMIN TALBOT (President-Elect), in opening the discussion, said that as one who had the privilege of knowing the author for many years, he desired to compliment him for having produced such an excellent paper. As he rightly said, it was in the 'nineties that the conditions were created, the outcome of which was that in the beginning of the new century the great iron and steel people came to sanity. At that time he was engaged in the management of one of the works in the East; he used to visit the author in Chicago at the Illinois Steel-works. The competition which was forced upon Chicago from Pittsburg was very keen indeed, and prices went down to such figures that would hardly be thought possible at the present time. That brought together the financial men, who did not see why such competition should continue, as it meant, of course, the elimination of a great many people, and the result was the formation of the U.S. Steel Corporation.

The paper, in his opinion, was of great importance, not only to a technical society like the Institute, but also to affiliated federations, especially those which had to deal with labour, because some of the principles discussed therein had been obtained, not by means of labour unions at all, but by means of the open shop—in other words, non-union labour. Everything—and more than what outside agitators, with whom we had had to contend for so many years, claimed could only be obtained through them—had been obtained by individual committees in direct communication with their companies and their works, so that each knew what it was possible to attain. That, to his mind, was one of the outstanding features of the paper. The author stated that although there was almost a continuous fall in their prices high wages had been obtained. That was entirely due, in his opinion, to the increased output of the individual American workman. America was greatly favoured because she had a wise policy. She knew that there was an increasing demand for iron and steel, but she did not know the limit of it yet. Consequently, there was always what was called in Great Britain "a backbone order," which was a safe foundation to build upon, and it was possible to go ahead with new machinery and new ideas, knowing that if they were successful they would be remunerative. Plants had lately been built in this country which were quite as good in certain departments as those in the States, but it was necessary to have a constant supply of orders to enable the plants to be operated continuously, otherwise good results could not be obtained. There was a striking difference in the wages *per capita* in the two periods which the author mentioned, but again that was obtained by the increased output per man; they increased from 825 dollars in 1902 to 1870 dollars in 1926.

He would like the author to give a little further information concerning his statement that until 1922 the works were operated universally on 12 hours' continuous operation, but since that time the present 8 and 10 hours' working schedule had been adopted, and a 7-day week had been replaced by a 6-day week. It looked to him as if in that statement there had not been an automatic cutting down to 8 hours all through, which had been forced upon us just after the war—rather hurriedly, to his mind. Probably if they had postponed it for a while the industry would have had more to say about it. There were certain operations which all agreed should be 8-hour operations; there were others about which there was a very divided opinion, and something must have occurred in the industry in the States, because there were 8 and 10-hour days adopted in the works. He noticed that the author in taking out the figures for the return which capital had obtained had taken the whole country into consideration. He thought better results would have been obtained if the author had taken only the figures for his own Corporation and the returns which they had obtained in the shape of profits and dividends. He remembered that when the Steel Corporation was formed, people said that the common stock was watered; it was sold for ten cents per dollar, or, at any rate, at a very low price. As one who happened to be a small shareholder, he had received a copy of the balance-sheet since the formation of the Corporation, and it contained some very interesting figures from the point of view of their cumulative effect. Owing to the great business ability of the late Judge Gary and his associates, the shareholders had not only received a decent or reasonable return on their capital, but the assets had increased enormously, and lately the reserves grew so big that bonus shares had been distributed. That was evidence of good management over a long period of years.

With regard to the great campaign which had taken place in connection with welfare, safety, sanitation, and so on, he doubted if those great improvements would have been attainable if a combination had not been brought about. Owing to those great causes the Americans had obtained very great advantages which would not have been possible under that conception of business, prevalent in the decade of 1890 to 1900, which was summed up in the phrase: "Each man for himself, and the devil take the hindmost." The stabilisation of prices which the Steel Corporation had brought about had been, to his mind, a very great advantage to the United States of America.

Sir WILLIAM LARKE, K.B.E. (Hon. Member of Council), said he was sure the members were very much indebted to the author for answering what, to many people in Great Britain, had been a wonderful riddle—namely, how the United States had obtained the results which that country had enjoyed during a period when the experiences in this country had been far different. Among the many telling phrases which the author had incorporated in his paper he desired to refer to two,
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which he thought gave the complete answer. One was at the bottom of p. 16, where the statement was made: "A vital factor in the development of the twentieth century, and one which has been especially emphasised in the United States since 1914, is the multiplication of individual effort rather than the effort of multiplied individuals." He hoped that phrase would be broadcast throughout the British Press, and be pondered and considered in labour circles. On p. 17 the author stated: "The larger the output of the individual workman, the greater is the tendency to lower costs, and the greater the possibilities of return in wages and in dividends." A great deal had been heard about the secret of high wages. In his opinion there was only one secret of high wages, and that was low costs. That was the whole solution of the problem of high earnings on the part of labour. He desired to emphasise that still more in Great Britain, where, for reasons that he could not enter into at the moment, they had experienced perhaps a not unnatural high cost of living, when all the financial circumstances, and burdens of taxation which this country was supporting, connected with the aftermath of the war, were taken into consideration. They were all striving to improve the standard of living of the workers and of the people generally, and that standard of living could be improved more quickly by a reduction of costs than by any attempt to increase earnings on present monetary levels. In a country such as the United Kingdom, which depended on its export trade for 50 per cent. of its products, it was clear that costs must first of all be reduced in order that it might dispose of those products; and if they reduced their costs with the same income it was equally clear that they reduced the index of commodity prices and increased the standard of living, since decreased costs increased the purchasing power of money—an axiom that was frequently forgotten, particularly in labour circles. One of the interesting things the author had shown was that in the United States the development of industry had been, as it had been indeed since the industrial revolution in all countries, from small productive industrial concerns to larger corporations; but the United States had swung the full circle. They had now come back to the position in which the individual worker had become a capitalist. The individual worker had become a capitalist, because with large combinations more efficient organisation had become possible. Lower costs and increased production *per capita* had produced a surplus of wealth in which the worker was participating, and he had now become part owner of the concern in which he worked. That was a condition which they desired to see existing throughout the industrial world in order to secure not only industrial peace but international peace.

He was very interested to note the enormous reduction which the Steel Corporation in the United States had experienced in the number of accidents. He was privileged to be in the Gary Steelworks in 1912, when the high percentage of accidents to which the author referred was then in operation, and he was amazed at the completeness at that date

of the safety-first arrangements and the educational campaign. There were safety-first committees for the instruction of the men ; there were slogans exhibited all over the works, some of which rather amused him ; for instance, such things as : " Take care of the other man, you may hurt him." " A careful man is sometimes efficient, the careless never," and so forth. Coming from a country with older traditions, he wondered how far such methods would be successful, and the author had given the answer to that question.

He desired, in conclusion, to say a few words on the subject of combinations. It was rather extraordinary that in the United States at present public opinion still lagged behind the view held in Europe. In the United States industry had led the combination movement. In Europe at present he thought it was safe to say that public opinion was leading the combination movement and industry was actually following it. There was one fallacy with regard to the combination movement which he never could understand, but it was frequently raised in this country, and he gathered from the author it was the cause of the anti-combination laws in the United States. It was that the consumer considered that a combination in regard to the product which he consumed must operate against him. He asked the consumer to consider whether those people who entered into combinations for the purpose of improving the efficiency of their industry were so unintelligent that by so doing they were likely to prejudice the consumer's interest on whom they depended for their prosperity ? Could anything be more fallacious or unintelligent than to enter into a combination for the purpose of more rapidly committing suicide by destroying the outlet for one's products ? Quite clearly combinations were designed to improve the efficiency of the organisation, and in so doing they benefited the consumers of the products which they produced. Therefore he trusted that combinations and organisations for improving the efficiency of production would not only receive, as they were receiving at the present time, the support but the stimulus and continued pressure of public opinion in this country, as it was only by means of such higher organisation that this country could hope to readjust itself to the post-war economic position, without a permanent contraction in the scale of its industry and a consequent increasing burden of unemployment.

Mr. R. SUNSTRÖM (Stockholm) said that in the United States labour had apparently not mixed up politics and economic questions. This was one of the reasons why the co-operation between finance, management, and labour had been so successful.

Mr. FRANCIS SAMUELSON (Past-President) said that he happened to read the paper in the train, and he looked at the first page particularly to see whether it contained the words " confidential until after the meeting." When he saw that it did not, he carefully left it on his seat

in the hope that it might fall into the hands of some working man, who would pass it on to his friends in order that they might have a talk about it. Very many wise things were said in the paper about increased production from the point of view of the producer, but it was extremely difficult to get those things said in the right way to the right people. Propaganda ought to be more on the lines of "subcutaneous injection" than on the lines more generally prevalent of holding a pistol at a man's head. If it were only possible to get a paper like the author's into the hands of the working man without his knowing how he got it there, it might do an enormous amount of good. He was speaking at the moment as though it were only the working man who wanted teaching, but everyone present knew that they required teaching just as much as the working man, but it was not quite as hard to get at them. To attempt to discuss the author's extremely interesting and able paper meant only to repeat bits of it in a different form, because the ground had been so thoroughly covered in the paper itself. The one outstanding fact that people on both sides of capital and industry did not always seem to remember was that wealth was really an accumulation of surpluses. It was only by producing a little more bread than was actually required to keep body and soul together that it was possible to have any means of getting a little butter and a little marmalade.

Professor HENRY LOUIS (Vice-President) said the only sentence in the author's admirable paper which was not quite clear to him was at the bottom of p. 22, where the author stated that the earnings for the years 1925 and 1926 were respectively 5.61 and 6.70 per cent. on the capital invested. He hoped the author would be good enough to say whether that included interest and depreciation and redemption of capital or not. Obviously in an industry with wasting assets, such as the mining industry in which he was so largely interested, that question was a very vital one. It was perhaps less important in iron and steel works, but nevertheless it was an important question.

The author had made it perfectly clear that America had an advantage over this country, not only in the "open shop," but in the attitude of the Unions. The American Unions never dreamt of advocating a "ca' canny" policy, and, if they did, their members would not listen to them. As an illustration of that he would mention an instance in which it could not be said that either natural advantages or plant or mechanical power came in, and that was the bricklayers' trade. As they all knew, in this country no bricklayer dare lay more than 500 bricks a day. An American contractor told him that he would not have a man on the job who could not lay 2000 bricks a day. That was the kind of difference which the paper brought out very clearly indeed.

Sir WILLIAM ELLIS, G.B.E., D.Eng. (Past-President), said that his only reason for adding a few words to what had already been said was that, as one of the Past-Presidents, he desired to express his ap-

preciation to the author for his valuable contribution. He remembered during his visit to the States that he was very much impressed with the desire of Americans that he should tell them what his opinion was. He thought that was an experience that a great many visitors to the United States had had. He desired, in the first place, to congratulate the author on a terseness of literary style in the paper which he thought was ahead of anything of the kind which had been read at the Institute for a very long time. There were certain telling phrases in the paper which he hoped they would have the courage to air in this country before an audience to which they might not be very acceptable. He did not know to what extent the author realised what the difficulties in Great Britain were in connection with industry and labour. He would like him to go away from this country with the impression that, although its difficulties had been enormous, almost crippling to the country, there were already some indications that the spirit of political animosity and the desire not to advocate on all occasions peace in industry was to some extent passing away. The evidence in that respect recently forthcoming at the Trade Union Congress was encouraging; it was very different from what was heard a year ago. At the present time they were doing all they could in steelworks to introduce labour-saving appliances with a view to economy in industry. He desired to ask the question: With all the unemployment that existed in this country, ought not their interests to be in introducing what would increase the amount of employment and not decrease it? Nevertheless, they were forced into the position of introducing all the labour-saving appliances they could because of the high cost of production. The author had touched on that point very ably, that it was necessary to adopt the principle in this country and realise its soundness, that the more effort each individual, whether employer or workman, put into his work, the more he produced, the greater the prosperity that would result. That principle had not yet been wholeheartedly adopted in this country.

Mr. JOHN CRAIG, C.B.E. (Member of Council), said he desired to take the opportunity of thanking the author for contributing a paper which would in itself make the present meeting memorable. Some years ago he had a conversation with a member of the late Labour Government, in which the latter castigated him, as representing the employers, for his ignorant and non-enlightened attitude towards labour, suggesting that if employers wanted to learn something that would be useful to them in regard to the proper treatment of labour in this country they should apply to America. He would ask the Secretary for an extra copy of the paper to send to that member of the late Labour Government, as it contained the reply of America to the difficulties connected with labour which existed in Britain. The author had not suggested that he had come to this country to teach the people anything; it was possible for them to draw their own conclusions. Personally,

he was not going to suggest that it was possible to hope that the conditions which now existed in America and which had made her so prosperous were ever going to obtain in this country. There were certain things in Britain which were not going to be easily remedied ; and he was afraid that, much as they might desire to see certain of the striking features of American industry introduced into this country, they were not possible. He did not think it would be possible to adopt them ; and it would therefore be necessary to struggle on, seeking to improve things along lines somewhat different from American lines, and, therefore, lines which were much more difficult.

One could readily see that America had profited in many ways by the fact that she had made so much money. He thought he was right in saying that the enormous increase in the output of American steelworks had been obtained at a very trivial increase on capital account ; and when one realised that state of affairs, it was possible to appreciate that in her selling prices for steel she had obtained not only a return for the three parties named in the paper, but also a very reasonable return for the remodelling of her plant. That had made her the envy of all other countries. One thing that Great Britain regretted very much was that it was not able to utilise America, as it did in earlier days, for exporting iron and steel to her. Although he did not claim to be very old, he could well recall that in periods of depression in Britain manufacturers found a most useful outlet for a part of their production in the United States. But the United States, wisely or otherwise, very speedily put an end to that enterprise on the part of Britain. If America had refrained from adopting that measure for ten or twenty years, it might have been the case that the British steel trade would have been in a more efficient condition than it was at the present time ; but America had made quite sure that very little steel passed from this country over her borders.

Great Britain was hampered in many ways, and had to fight against many difficulties which were extremely great. There was a certain public opinion existing in the country which was to the detriment of the iron and steel trade, because it was thought to have made an abundance of money during the war which it should have conserved. Those who were more intimately acquainted with the facts of the case knew that was not so. It might interest the author to know that by means of the excess profits duty and a very largely increased income-tax the Government made quite certain that iron and steel manufacturers were left with no more money at the end of the war than they had at the beginning. That fact was not sufficiently recognised in this country, and manufacturers were charged with lack of enterprise and development ; but he was sure the statements he had made would be borne out by all those who were acquainted with the inner workings of the industry. Some things were left to the steelworks, such as additional plant ; but that plant had been the means of extracting further money from the industry owing to the fact of increased local taxation. If the

author lived in this country for a little longer and became better acquainted with the iron and steel trade, it would be useful to obtain from him his opinion as to how the present state of affairs was to be remedied.

He had not made his remarks in the spirit of criticism ; but he was not optimistic enough to believe that the inbred traditions of Great Britain in regard to labour and other matters would enable the people here to apply the conditions that existed in America with any great measure of success. It would only be by the inculcation of the great truth of increased earnings that there would be a tendency on the part of labour in this country to recognise that the restrictions imposed had created difficulties for themselves and had reduced the possible earnings of the working people. He trusted that many of the striking things which had been said by the author would be borne in mind by the members, because he was sure they would be most helpful in making the iron and steel trade a progressive one, worthy of the Old Country.

The Hon. R. D. KITSON, D.S.O., M.C. (Member of Council), said that years ago things were done which would not even be thought of nowadays. He knew of a mill, many years ago, where the reasonable output of a certain article was 400 per day, the men being paid so much per shift. By working very hard the men could increase the output to 800 to 900 per day, yet the rate of extra pay was fixed at only 6d. per 100. He ventured to say that nowadays no one would think of offering such a low reward to the workmen for their increased activity.

Mr. E. A. ATKINS (Warrington) agreed that the author had been very wise in the presentation of his paper. He had told quite an unvarnished tale of what had been done in America, without making any effort at all to apply it to what might be done in Great Britain. They had learned that co-operation between the managers, the technical side, the men, and so on, had brought about a condition of great prosperity in the States. He thought it ought to be borne in mind that economic conditions in this country were entirely different. It was mentioned by an intelligent writer in the last issue of *Industrial Peace* that steel manufacturers were handicapped to an extent of no less than 15 per cent. against continental manufacturers. That writer said that continental currencies were about 10 per cent. under-valued, whilst British currency was 5 per cent. over-valued, and to that extent the British manufacturer was penalised. But the paper contained many points which ought to be applied to this country. There had not been much discussion concerning the possibility of the unification of the steel industries in this country. It was true that certain statements had been made that some works went on in their own individual way at about "half or quarter cock," and the question arose whether the

time was not ripe for considering some way by means of which the various works in Great Britain could be joined up, so that it would be possible to arrive at a condition in which steel was produced very much more cheaply than it was at the present time. He knew it was often contended that over-capacity existed in this country. If that over-capacity existed he thought the sooner they chopped some of it off the better. The paper referred to the fact that the workers themselves had invested in the iron and steel industry. Personally, he doubted whether it would be wise for any workmen here to invest their very scanty savings in the iron and steel industry, as a good many of the firms were paying no dividends at all. It must be borne in mind that in this country they had not yet arrived at that state in which the best co-operation in industry could be obtained. He did not wish to mention any particular groups of works, but he was sure this country should emulate America by getting different types of men on the directorates, who might be more helpful than directors were at the present time. He thought a great deal more could be done by a very careful study of the staffs of the various works, with the object of making quite sure that the best type of man was obtained irrespective of influence. He was quite sure there were many lessons in the paper which could be learned by the leading men in the iron and steel industry if they would only get together and carefully study them with the object of applying them without fear or favour.

The PRESIDENT said it seemed to him that the key-note of the paper could be summed up in the words "co-operation based on confidence." In America the workman realised that if he did the work he would receive the pay, and the employer realised that if he supplied the necessary capital to provide up-to-date machinery, he could rely upon its being worked to its full capacity, and this led to a large individual output. It encouraged co-operation between employer and employed with the one object of obtaining as large an output as possible, and established that identity of interest which was so essential for effective co-operation.

The big combinations which had been so successful in America had not been operated with the idea of creating a monopoly, but, as suggested by the author, to reduce the cost of production. It did not necessarily follow that because costs were low, wages would be high, but high wages were only possible with large individual output, by which low costs of production could be obtained.

Mr. ROBINSON, in reply, thanked the members for the kind and courteous treatment that he had received. He offered to the Institute with some trepidation his paper on a non-technical subject, but he hoped that the facts presented would be of interest, and it should be emphasised that the conclusions drawn appertained distinctly to the United States. It might well be the case that among the facts given there were some items of interest which were of possible application in

England, but it would be presumptuous on his part to make more than a suggestion along those lines.

Mr. Talbot had referred to the question of hours of labour. Up to comparatively a few years ago the iron and steel industry of the United States was essentially on a twelve-hour basis for continuous operation and ten hours for non-continuous operation, with the seven-day week under general observance. Partly on account of the economic situation involved and partly due to the force of public opinion that a man ought to be able to earn a living wage without working more than six days a week or as long as twelve hours a day, the present eight-hour, ten-hour, and six-day week schedule was adopted. Curiously enough, there was no little opposition on the part of many of the men toward that change.

Reference had been made to the amount of earnings in the iron and steel industry. He wished to state that for the years 1925 and 1926 the percentage of $5\frac{1}{2}$ and $6\frac{1}{2}$ per cent. which he had given as earned on the capital invested was the amount earned after depreciation had been deducted from the profits made. It should be noted that those earnings were not based on the capitalisation of the concerns involved, but rather on the amount of money that was actually invested by them. The published balance-sheets of steel companies representing over 85 per cent. of the United States ingot capacity to which he referred in his paper were compiled and published by the *Iron Trade Review* in March 1927. It would be noted that the average earnings of all the companies concerned closely approximated the earnings of the United States Steel Corporation. In that connection it should be remembered that for a number of years the Corporation did not pay any dividends on the common stock, and when it did begin to make a distribution it was for many years on a 5 per cent. basis. The Corporation's earnings to-day were quite largely influenced by the fact that it had conservatively "ploughed back" a large amount of money into the industry.

He cordially thanked the members for the kind reception they had given him, and he expressed the hope that collectively or individually they would visit America and see all that was to be seen. Everything was open to them, and the American iron and steel manufacturers were always glad to see their English friends and to answer their questions. He felt convinced that the British iron and steel manufacturers had better times ahead of them, and he expressed the opinion that it would be helpful if there were closer co-operation between the wonderful organisation that the Institute represented and their colleagues in America.

THE USE OF SILICA GEL AS A MEDIUM FOR DRYING BLAST.¹

By EDWIN H. LEWIS, M.A. (WISHAW).

THE varying amount of moisture in the atmosphere and its effect on blast-furnace practice has, for a long time, been of interest to ironmasters. It is 127 years since the first essay, read at a meeting at Bradford of the Principal Ironmasters in the Counties of York and Derby by the first President, Mr. Joseph Dawson, dealt with this subject.² Similarly, at the inaugural meeting of this Institute, the Duke of Devonshire referred to the question as one of importance.

Figures showing the hourly variation of atmospheric moisture were given by Gayley in his classic paper before the Institute in 1904.³ No complete records over a long period of the moisture at Wishaw have been taken. Figures, however, taken in the West of Scotland confirm the relative variations, although in the Scottish climate the maximum moisture does not reach so high a point as that observed by Gayley. Half-hourly readings at Wishaw taken from the middle of April show the following maxima and minima :

1927.	<i>Maxima.</i>	<i>Minima.</i>
	Grains per cu. ft. of Atmosphere.	
April	4·70 (18th)	1·11 (27th)
May	5·88 (8th)	1·47 (10th)
June	5·57 (16th)	1·33 (12th)
July	6·51 (10th and 30th)	3·62 (16th)
August	6·56 (7th)	3·26 (30th)

The importance of these figures will be realised more readily if it is borne in mind that each 0·5 grain per cu. ft. in the blast represents about 10 lb. of water per ton of pig iron made. In order to trace the result of monthly variations on the output of

¹ Received August 10, 1927.

² The paper is reprinted in full in *Journal of the Iron and Steel Institute*, 1907, No. II. pp. 221-242. T. S. Ashton, in "Iron and Steel in the Industrial Revolution," refers to this body as the "Friendly Association."

³ *Journal of the Iron and Steel Institute*, 1904, No. II. pp. 274-300.

pig iron, some figures were taken out, and showed in the case of one furnace 1.5 per cent., and in the case of another furnace 3.0 per cent., difference between the four summer and the four winter months.¹ As a further test the average ratio ore/coal was calculated for ten pre-war years for all the furnaces in blast, and is reported in Table I.:

TABLE I.

	Ore/Coal Ratio.	Grains per cu. ft.
December	1.0538	2.6
January	1.0451	2.6
February	1.0356	2.6
March	1.0428	2.5
April	1.0213	3.0
May	1.0390	3.7
June	1.0255	4.2
July	0.9955	4.8
August	1.0109	4.9
September	1.0233	4.2
October	1.0390	3.6
November	1.0188	2.9

In Scottish practice the weight of air used per ton of pig iron is about 10 cwt. more than the total weight of all other materials charged into the furnace. So that if much care is taken in selecting, sizing, and conditioning the other materials, it seems only logical to get the air also into the best possible state.

Again, there are so many variable factors in blast-furnace operation, that it is desirable, if possible, to pin down one of the variables. The desirability of constant blast moisture is generally agreed, if such a result can be procured at a reasonable initial and running cost.

Many attempts have been made, and processes suggested, to obtain such a constant blast, either by freezing or by absorption of the moisture chemically with calcium chloride, sulphuric acid, &c. There has been much discussion concerning the merits of these processes, and the criticisms can be summarised under three heads :

- (1) That the absorption methods have proved impracticable.

¹ See *Industrial Fatigue Research Board Report No. 5, 1920, p. 17.*

- (2) That freezing is too expensive in maintenance and running costs in comparison with the results obtained.
- (3) That in all cases the money spent would have been better spent in improving other conditions, such as increasing the blast temperature.

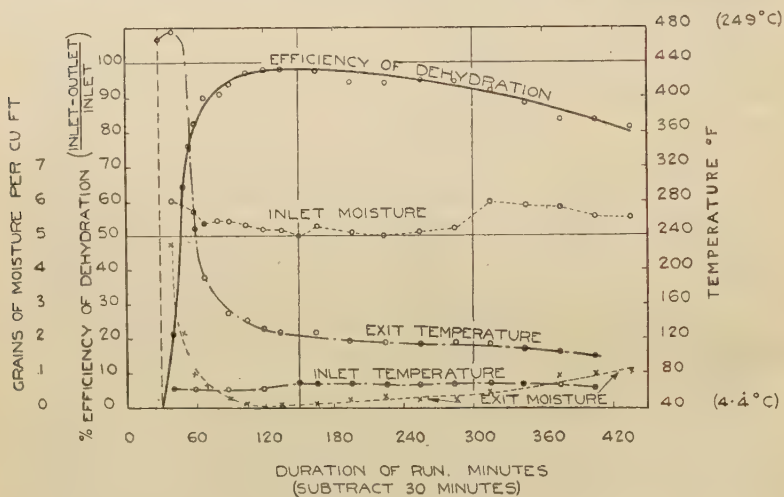
At Wishaw the blast temperature is from 1450° to 1500° F. (788° to 816° C.), and it is not possible to raise it without danger to the refractories in the stoves. Although the possible savings from the use of dry blast are not so great at such a blast temperature, it still seemed possible to improve the efficiency of the furnaces if dry blast could be obtained at a moderate cost.

A few years ago the use of silica gel was suggested. This material, which is now made in large quantities and of uniform quality, has wonderful powers of adsorbing water. Its properties were described by Mr. E. B. Miller before the American Institute of Chemical Engineers in Montreal, on June 28, 1920. The main features from the blast-furnace point of view are that at atmospheric temperature it can adsorb up to at least 20 per cent. of its weight of water from the air with an efficiency of 99/100 per cent., and that by raising the temperature this water can be driven off, leaving the reactivated gel ready for another cycle. It is not advisable to reduce the water content below about 5 per cent. In practice it is desirable to have about 2 lb. of gel for each cubic foot of air to be treated per minute. Fig. 1 shows a typical efficiency curve for an adsorption run in one unit.

A plant to treat 35,000 cu. ft. per minute has been erected at the Wishaw Works of The Glasgow Iron and Steel Co., Ltd., and has been in operation since April 13 of this year.

The plant contains six adsorber units. Each unit consists of a large steel box, in which are placed trays containing the gel in granular form (see Fig. 4, Plate I.). The bottoms of the trays are perforated, and the latter are so arranged in the box that the air passes through them in parallel. At one end of each box are valves communicating with the atmosphere or with the activating gases. At the other end are similar valves which allow either the air to pass to the blower, or the gases and water vapour to pass to a small exhaust fan which is used for activating. Five units are

normally used for adsorption while the other one is being activated. At the atmospheric inlet "Visco" filters are placed to remove the dust which is always found in the atmosphere of an industrial district, and which would, if pulled into the gel beds, tend to clog them and increase the suction ($1\frac{1}{2}$ in. to 2 in. water-gauge) necessary to draw the air through. The heat for activation is provided by the combustion of blast-furnace gas, which has been cleaned in the process of recovering the by-products from the raw coal



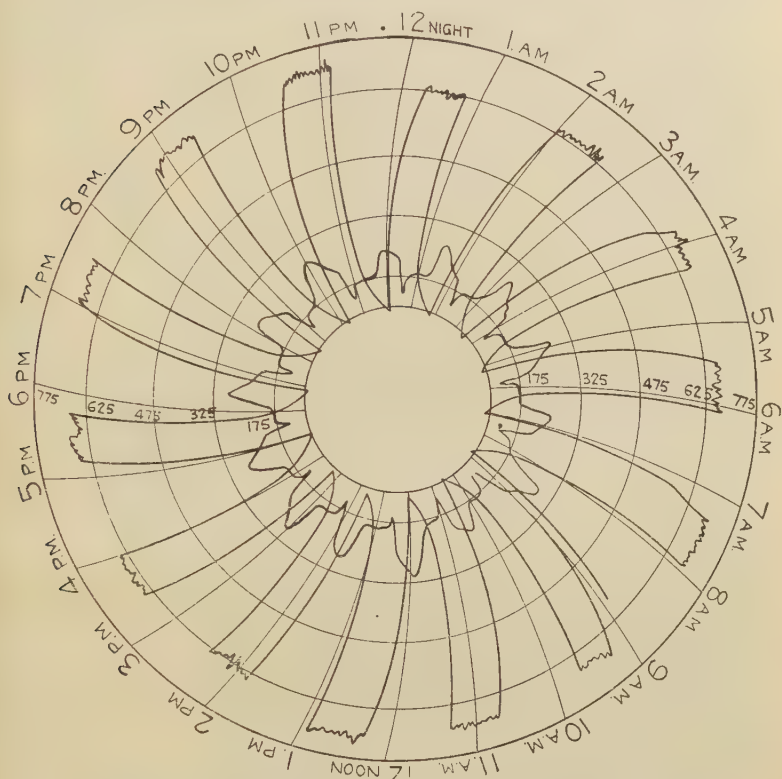
455 lb. OF DRY GEL - 246 CU FT AIR PER MIN

FIG. 1.

used in the furnaces. The gas is burnt in a small combustion chamber, a photograph of which appears in Fig. 5 (Plate II.), and an excess of air is admitted to reduce the activating gases to about 640° F. (338° C.). Fig. 2 is a chart of activation temperatures at the inlet and outlet of adsorbers. All the air used for combustion and dilution is also passed through "Visco" filters. The normal period for the activation of one unit is about $1\frac{1}{2}$ hours. During the latter part of this time the gas is turned off and air only is drawn through to cool down the gel and bring it to an efficient condition for adsorption. The valves at the two ends of the boxes are coupled together so that the "reversing" of a unit is done in a single operation. The gas is of about 135 B.th.u. per cu. ft.,

and the maximum amount required represents the equivalent of about 7 tons of coal per day.

Between the dehydrating plant and the blower there is an



Thermograph Range, 100° to 1000° C. Date, Aug. 5, 6, 1927.

FIG. 2.—Autographic Chart of Activation Temperatures—Inlet and Outlet of Adsorbers.

adjustable inlet for atmospheric air, which is used for diluting the dried air up to the moisture figure aimed at. If this were not used it would be difficult to maintain a constant moisture. In cold weather the plant has given a degree of dryness far below anything achieved by Gayley. Fig. 3 shows how, by means of this door, it is possible to maintain a constant moisture content in the blast.

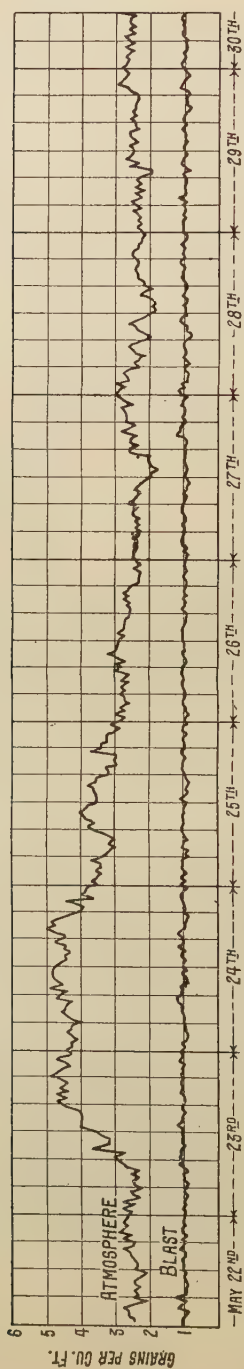


FIG. 3.—Half-hourly Record showing the Amount of Moisture in the Blast and in the Air before Drying.



FIG. 4.--Adsorber Unit complete with lengths of Ducts and Inlet Cowl.

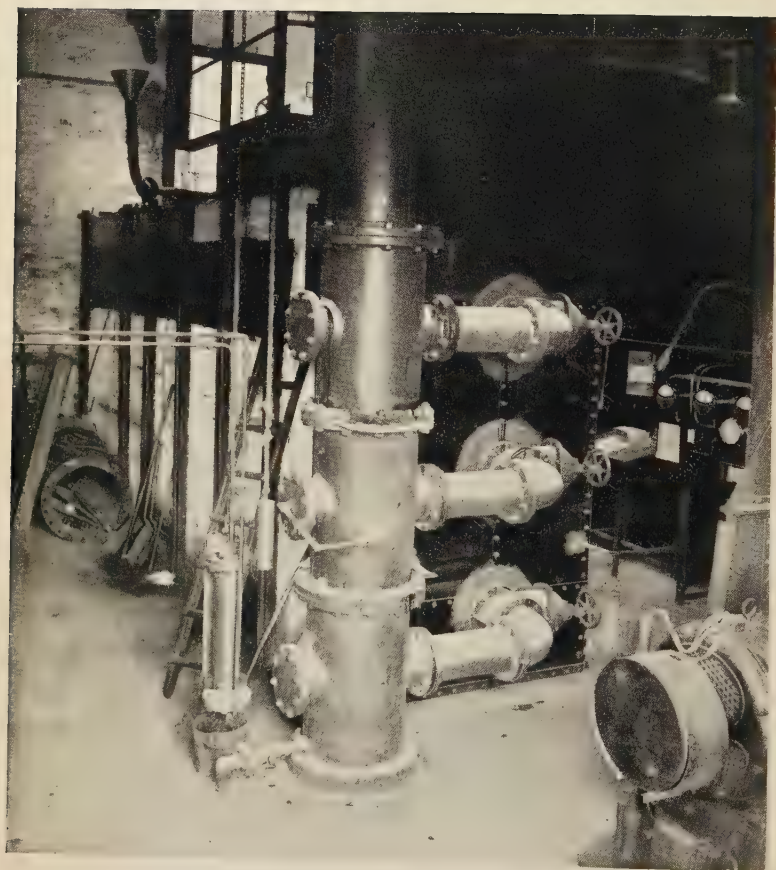


FIG. 5.—Combustion Chamber for activating Gases.

It is not easy to give absolutely definite results from the use of dry blast under Scottish conditions. With a number of small furnaces blown at constant pressure from a common main, and making different qualities of iron, many other variables come into the picture. Then again the true blast-furnace gas is so diluted with the "coke-oven" gas formed in the upper part of the furnace that the effect on the CO/CO_2 ratio is difficult to observe. In 1925 the Wishaw Works produced the largest amount of iron recorded in their history, and the fuel consumption was the lowest for many years. It is the latest unbroken year, so that in Table II. it has been taken as a standard. In May, June, July, and August of this year (1927) the dehydrating plant has been in continuous operation, although, being the first of its kind ever built, it is still in the stage of minor adjustments which is common to all new plant.

TABLE II.

	1925.	May, 1927.	June, 1927.	July, 1927.	August, 1927.
Moisture in atmosphere. Grains per cu. ft.	3.5	3.08	3.41	4.85	4.77
Moisture in blast. Grains per cu. ft.	3.5	1.09	1.20	1.61	1.50
Output per furnace per week. Tons	356.5	418.5	400.0	417.6	412.9
Percentage increase in output . . . . .	...	17.39	12.20	17.14	15.82
Total carbon per ton of iron. Lb.	2055	1961	1938	1956	1947
Percentage saving in fuel . . . . .	...	4.57	5.69	4.82	5.55
Carbon burnt at tuyeres per ton of iron. Lb.	1705	1611	1588	1606	1597
Percentage saving in fuel burnt at tuyeres . . . . .	...	5.51	6.86	5.81	6.33
Balance of available hearth heat per lb. of carbon burnt at tuyeres (according to Johnson). B.t.h.u.	1585	1724	1717	1694	1700
Theoretical saving in carbon burnt at tuyeres (according to Johnson). Per cent. . . . .	...	8.06	7.69	6.43	6.76
Theoretical balance of available hearth heat per lb. of carbon burnt at tuyeres for actual atmospheric moisture for month . . . . .	...	1609	1590	1509	1514
Theoretical saving in carbon burnt at tuyeres for actual monthly conditions. Per cent. . . . .	...	6.67	7.39	10.92	10.94

The above figures require some explanation.

Moisture in Blast and Atmosphere.—The figure for 1925 is taken from the average of the district. The figures for 1927 are the averages of half-hourly spot readings taken at Wishaw.

Output.—Since 1925 some slight changes have been made in the lines of three out of the five furnaces now in blast. An analysis of the individual furnace returns shows that not less than $7\frac{1}{2}$ per cent. of the increase is apparently due to drier blast.

Total Carbon Used.—These figures are taken from the quantities of coal and coke used, and their analyses.

Carbon Burnt at Tuyeres.—This is obtained from the total carbon used by deducting 350 lb. per ton of iron as an allowance for solution loss and direct reduction. The actual quantity of 350 lb. is taken from results tabulated by Mr. E. C. Evans from a large number of furnaces using similar ores.¹

Available Hearth Heat.—Wishaw conditions have been assumed, namely, critical temperature 3000° F. (1649° C.) and blast temperature 1450° F. (788° C.), for the purpose of applying Johnson's theory. The balance of heat available per lb. of carbon burnt is shown below :

Grains per cu. ft. of Water in Blast.	B.th.u. Available per Lb. of Carbon Burnt.
Nil	1788
1	1729
2	1671
3	1613
4	1557
5	1501
6	1446

The correctness of Johnson's theory is a matter of controversy ; certainly his figures seem to agree closely with the actual savings obtained. It will be interesting to see whether future results show such close approximation to his theory.

The last two lines in Table II. are intended to show the theoretical saving in fuel burnt at the tuyeres for each month, taking as a standard for comparison the actual atmospheric conditions for the month instead of the atmospheric conditions for the whole year 1925.

A point in favour of constant moisture in the blast is the

¹ *Journal of the Iron and Steel Institute*, 1927, No. I. p. 177.

more regular quality of iron produced. This is the experience at Wishaw, but cannot easily be put into figures. The fuel saving, in the case of furnaces on special hematite, must give a small but important reduction in the total phosphorus and sulphur charged into the furnace.

The costs of running such a plant are small. The only moving parts are the hand-operated valves and the motor-driven activating fan, which takes 20 H.P. The maintenance costs should also be low.

The financial saving requires to be worked out for each individual case according to local conditions. The amount of fuel saved will depend largely on the blast temperature and the average moisture in the atmosphere; its value on the cost of fuel and the cost of limestone required to flux the ash in the fuel. The further saving in cost per ton will depend on many factors, such as the proportion of the wages cost which represents time wages as distinct from tonnage, the overhead charges, &c. In Scotland if the increase in output exceeds the saving in fuel and there is consequently a bigger coal consumption, overhead charges per ton in the by-product plant will also be reduced, and the net cost of coal will be less.

There does not appear to be any loss of tar with the changed conditions. On the other hand, there is a slight diminution in ammonia recovery, which may be due to the smaller amount of hydrogen in the gases, or may be due to the increased difficulty of cooling the gas, with a bigger coal consumption.

The saving will not be quite as attractive to those who need their blast-furnaces to act also as gas-producers. Taking everything into account, the plant at Wishaw, so far, shows a substantial return on the capital cost.

An interesting question arises as to what is the best degree of dryness in the blast. It seems to be generally agreed that improved furnace operation follows with increased dehydration down to 1 grain per cu. ft. On the other hand, it is known that certain reactions in the furnace are slowed down when the gas is below "calcium chloride" dryness, which represents about 0.1 grain per cu. ft.¹ What happens in between does not seem

¹ Bone, Reeve, and Saunders, *Journal of the Iron and Steel Institute*, 1927, No. I. p. 155.

to be known. Silica gel offers an opportunity of exploring the unknown field between 0.1 and 1.0 grain per cu. ft., and it is hoped at Wishaw at a later date to venture into this region.

For controlling such a dehydrating plant hygrometry becomes important. So far, the readings have been taken with wet and dry bulb thermometers, care being taken to provide sufficient draught and to keep the wick continuously wet with clean water. A recording hygrometer which would give direct readings in grains per cu. ft. would be a great advantage, if the instrument makers could produce one.

The author is indebted to Mr. Edgar C. Evans for the appended historical notes and list of references.

HISTORICAL NOTES.

1800.—J. Dawson of Lowmoor, in a paper read at Bradford, pointed out the difference between winter and summer practice.

1853.—Prideaux's "Economy in Fuel" gave suggestions for drying blast.

1869.—The Duke of Devonshire, at the inaugural meeting of the Iron and Steel Institute, mentioned this difference as an important problem to be solved.

1880.—The Fryer process, using solid calcium chloride. The liquor formed was to be collected and concentrated, and the solid so obtained dried and fused, but the process was not worked commercially.

1885.—The Cremer process, using solid calcium chloride or sulphuric acid. The medium was to be placed on double-bottomed trays, thus allowing for regeneration *in situ*. (Cremer was Gayley's predecessor—the process was unsuccessful.)

1890.—Gayley's experimental work on refrigeration begun.

1901.—Notes on experiments were made in the U.S.A. with a view to drying by refrigeration; a plant was to be installed at one of the Carnegie blast-furnace plants.

1904.—Gayley's paper before the Iron and Steel Institute, giving the first month's figures from Isabella No. 1 furnaces.

1906.—In a discussion of a paper by Meissner¹ Gayley stated that the saving to be expected directly from dry blast was normally about 3 per cent. with a maximum of 7 per cent., and that the remainder of the saving actually made was due to greater regularity in blast-furnace operation.

¹ *Transactions of the American Institute of Mining Engineers*, 1906, vol. xxxvii. p. 201.

The Elsner process, using solid calcium chloride, the regeneration being carried out in a lower drum, and the regenerated chloride then elevated to an upper "drying drum."

1907-9.—Refrigerating plant installed at Dowlais-Cardiff plant, and considerable savings quoted.

The Harbord process, using calcium chloride, sulphuric acid, &c. Peat or pumice stone impregnated with the medium, thus giving an increased surface area of the latter. Refrigerating plant installed in South Chicago to deal with 122,000 cu. ft. of air per minute.

1909.—Experiments were undertaken at Clarence Ironworks to determine the effect of uniformity of moisture content. It was shown that considerable quantities of steam could be added to the blast to attain regularity without materially increasing the coke consumption.

1910.—Daubin  and Roy described a calcium chloride process in which the blast was drawn through the chloride, which was water-cooled and arranged for regeneration *in situ*.

A plant was installed at Differdange Works, Luxemburg.

1911.—An ammonia refrigerator plant to be driven by exhaust steam was installed by the Brymbo Steel Company. The moisture was to be maintained below 1.5 grains per cu. ft.

The Miles process, a modification of Gayley's process, whereby the air was cooled in contact with sprays of cold liquid on the outlet side of the direct-acting blowing engines.

1913.—Ehrenwerth stated that the Gayley process at the Deutscher Kaiser Works, Bruckhausen, and the Daubin  and Roy process at Differdange, were out of operation and reported to be unsatisfactory.

1917.—Cammen described a process using calcium chloride solution, in which the brine flowed counter-current to the blast and was then taken to an evaporator and subsequently cooled.

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DISCUSSION.

Mr. WILLIAM SIMONS (Member of Council), in opening the discussion, said he rose with very great pleasure to express the satisfaction which he was sure all the members felt at the very excellent way in which the paper had been presented, and to congratulate the author on the courage and judgment he had shown in bringing forward what was an entirely new process in the industry. As he had pointed out, the extraction of moisture from the air was not new. The first practical application of it was in 1904, when Gayley read his paper before the Institute. At that time a great number of people followed Gayley's suggestions. Half a dozen plants were put up in the States; one was put up at Cardiff and, he thought, one was erected in Germany, but it was a very significant fact that none of them had survived except the one at Cardiff, which they only operated because it was there. The capital expenditure had been made, and the plant was therefore worked during the summer months. The author had very rightly given the reason for that. The cost of the Gayley process was very great, and very little compensation was obtained for it. Two days previously he had had the pleasure of seeing the silica gel process at Wishaw, and he was very much impressed with its simplicity. The only moving parts were the fan and the motor working it, contrasted with the Gayley system in which there was a 300-H.P. engine working the ammonia compressor, the brine pumps, and the condenser plant. It would therefore be seen at once by those who considered dry-blast of considerable advantage that the silica gel was a striking departure which would, he thought, very materially reduce the cost of extracting the moisture.

Whatever criticism he might have made in regard to the paper, the author had already anticipated. For instance, he stated on p. 45 that freezing was too expensive in maintenance and running costs in comparison with the results obtained. That, as he had already mentioned, was an undoubted fact. The author further stated that in all cases the money spent would have been better spent in improving other conditions, such as increasing the blast temperature. The conditions were not quite the same at Wishaw as they were at places where coke was used, or where blast-furnaces were contiguous to steelworks, and where it was necessary to take advantage of all the waste heat that existed. He did not know whether the author were not quite right in observing that the money might have been better spent in improving other conditions. At any rate, it was very important to get the highest efficiency in the stoves, to reduce the amount of gas that was used in them, and to get as much surplus gas available as possible in order to reduce fuel consumption in the works, particularly when it was found, as was the case in his works, that the value of the gas was reduced by the use of the dry air process.

Where there were only blast-furnace plants, then undoubtedly there would be an advantage in dry blast and considerable economy, although in his own works they had not found the economy that the author had shown in his tables. The author had shown that with a difference of about 3 or 4 grains an economy of 10 per cent. was obtained. That had not been the experience in his works, but their blast-furnace manager was of opinion that the furnace worked better and that there was an economy in coke consumption. With an economy of, say, $\frac{1}{2}$ cwt. or even up to $\frac{3}{4}$ cwt. of coke per ton, which they experienced, it was doubtful if this compensated for the reduced quantity and quality of the gas that might be used for other requirements, and the capital cost of the dry air plant. He was delighted at the enterprise which had been shown by the Glasgow Iron and Steel Co., Ltd., and, where dry blast was advantageous, he was sure the silica gel process was one of considerable value.

Mr. BENJAMIN TALBOT (President-Elect) thought Mr. Simons had referred to the key to the position when he said, in speaking of blast-furnaces as a department of a modern steel plant, that it was necessary to consider carefully the composition of the gas that would be obtained from the blast-furnace; if a bigger volume was obtained for use in the other departments he believed greater economy would be forthcoming. In other words, the blast-furnace was a more economical gas-producer than a separate gas-producing plant when gas could be produced as a surplus and used in other departments. Generally speaking, small coking coal was cheaper to buy than selected gas coals. Another point for consideration was the question of blowing by means of gas-engines, and it was necessary in that connection to consider the B.t.h.u.'s. The cutting down of the fuel to an absolute minimum was correct from the theoretical side; but it must be remembered from the practical side that if the fuel were brought down to a minimum and it were necessary to introduce elsewhere other appliances in other parts of the work, a full economic effect would not be obtained.

Mr. DAVID E. ROBERTS (Cardiff) said that he had had the pleasure of inspecting the plant at Wishaw. There were few mechanical parts, only a fan and a motor to drive it. As a means of drying air he thought the method under consideration deserved very careful study. It was impossible to tell until it had been in practical use for some years whether all the results that the author had given would be borne out in actual practice. He was one of those who had the pleasure of hearing Gayley describe his process in New York in 1904, and it seemed to him then that it had a tremendous future before it. But, unfortunately, partly due to the excessive cost of running the plant and for other reasons, it had not been such a success as was at first anticipated. In fact, when he was in America the year after the paper was read, some of the people who knew all about it told him that the results given

by Gayley's process fell short in actual practice, and that they were beginning to be disappointed with it. Whether the same disappointment would be experienced with silica gel he did not know. It was certainly an exceedingly simple arrangement. He presumed the great blotting-paper effect of the material was due to the fact that it was so exceedingly full of microscopic passages and pores that the actual superficial area of even a small piece of it ran into a certain number of square feet, and he understood that it could be used over and over again for years without any apparent deterioration.

The author stated that it was possible for money to be spent more effectively in other ways to improve the operations of blast-furnaces, and he was inclined to agree with him. Personally, he had always felt that dry air was right. He had looked into blast-furnaces using dry air and the combustion seemed to be better, while operators stated that the operations were more regular. On the other hand, he thought the feature of blast-furnace working in this country which needed the greatest amount of attention was the use that was made of the gas that came off the top of the furnace. Even at the present day in many of the works the gas was not even cleaned, and, worse than that, when it was cleaned it was not efficiently used. In the very modern equipments, which were kept at the highest pitch of efficiency, in Germany, America, and other places, it was noticeable how much trouble was taken to utilise everything to the greatest possible advantage. Mr. Talbot had stated that the blast-furnace was a producer, and that, within reasonable limits, was the way to look at it. He had heard it repeatedly said by blast-furnace people in this country that the amount of coke per ton used here was less than it was in Germany. That was easy to explain, the reason being that it was necessary to watch the coke, because the gas that was made was sometimes wasted. In Germany not a particle of it was wasted, and therefore it did not much matter whether they used half a hundredweight or even a hundredweight more of coke.

Mr. JAMES HENDERSON (Member of Council) thought there was no more important subject facing the members than improvement in blast-furnace practice in this country, and for that reason, if for no other, the paper was of first-class importance. There was always very great difficulty in establishing cause and effect in a blast-furnace, as there were so many variable conditions, so that it would be necessary to wait for some time to ascertain what practical results accrued from the use of the silica gel process. Referring to Table II., he desired to point out, for example, that in the month of June, during which the author said that special conditions were adverse to the working of the process, there was the best percentage saving in fuel of any of the months recorded. He did not put that forward in any critical spirit, but simply as evidence of the difficulty of making comparisons from month to month.

The author had very properly stressed in the first paragraph on p. 51 the regularity in the quality of iron produced. The speaker thought that was a most important factor. Of the materials used in the blast-furnace, the coke was in many cases outside their control and of a variable quality, and the same remark applied to the iron ores, some of which were more variable than others. In Lincolnshire, for instance, there were very great variations in the composition of the iron-stone. If one variable factor, moisture in the blast, could be eliminated, that alone must make for progress and better working.

He did not agree with those authorities who considered that the blast-furnace ought to be regarded as a gas-producer. On the contrary, he thought every effort should be made to cut down the amount of fuel consumed, even at the cost of reducing the quality in B.th.u.'s and the quantity of the gas that was obtained.

Professor C. H. DESCH, F.R.S. (Member of Council), thought the author's very important paper contained the first definite proof of the real value of dry blast, supported as it was by a carefully arranged set of figures. The process of drying by using some adsorbing material for the moisture, which had been tried at so many places, depended entirely on the perfect reversibility of the drying agent. He understood that the experiments made in Germany with calcium chloride failed because the process could never be made perfectly reversible. A very slight over-heating of the calcium chloride during reactivation spoilt it. The most remarkable feature of the silica gel material was that it seemed to be perfectly reversible. He had had occasion recently to watch the behaviour of silica gel in experiments entirely different from those of the author—very accurate and quantitative experiments on the adsorption of various organic vapours. One specimen of silica gel had been in use over and over again for three years for adsorbing all kinds of vapours. Recently the original specimen was put through the first experiment to which it had been subjected three years previously, and the curve of adsorption obtained for the vapour was exactly the same. Apparently its repeated use with a variety of materials had not affected the structure of the silica gel. That statement could not be made of any other drying agent, whether it was a dehydrating agent such as calcium chloride or a material such as charcoal, which acted by means of large pore surfaces as did the silica gel. There seemed to be every reason to believe that, provided tar and dirt were kept out of the plant, the silica gel would remain good indefinitely. In conclusion, there was one other point he desired to make. He naturally hesitated to criticise any statement made by Mr. Talbot, with his great practical experience, but he would like the question to be thoroughly discussed at the Institute, whether it was advisable to think of the blast-furnace as a producer and not to concentrate in the first place on its efficiency as a blast-furnace, subsequently looking to other means for obtaining better fuel values. He was glad

to hear Mr. Henderson's remark on that particular point, as he thought it was one of some importance.

Mr. GUY BARRETT (Epworth) said the author made the statement on the first page of his paper that each 0.5 grain per cu. ft. in the blast represented about 10 lb. of water per ton of pig iron made. He thought it should be noted that that could apply only to a particular practice. It was not a statement applicable to the manufacture of all pig iron. It would depend upon the amount of air consumed per ton of pig iron. It was stated that the drying required 7 tons of coal per day. He thought it would be useful if that consumption could be expressed otherwise, namely, as the amount of fuel per ton of pig iron. Reading the paper casually, the impression might be obtained that there was no fuel saving at all, because, taking into account only the amount of pig iron given in the table, the fuel saved did not amount to 7 tons per day. He presumed the explanation was that the 35,000 cu. ft. of blast was not used in one furnace but in several, and that it was the product of several furnaces which required the consumption of gas equal to 7 tons of coal per day. There could be no question at all that one of the most important things in the operation of a blast-furnace was the regularity of conditions, and, even if first of all money could be spent to better advantage in raising the temperature of the blast, he thought that if there were still a further saving to be made it merited investigation. He agreed with Mr. Henderson's comments regarding the suggestion that a blast-furnace should be considered as a producer. If that process were carried far enough, then the blast-furnace would not make the pig iron that was wanted.

The PRESIDENT was sure the members would wish to congratulate the author on a paper of a type particularly wanted at the present time. It gave the results of practical experiments on a large scale based on sound theoretical data, and was presented in such a way that both the theory and the practice were most clearly set forth. Although perhaps it was not for him to reply to the remarks of previous speakers but leave it to the author to do so, he wished to say that he did not agree with the remarks Mr. Talbot had made. On broad lines he thought it was most important that each unit, whether it was a blast-furnace or an open-hearth plant, or a gas-producer, should be made efficient in itself. If that principle were not adhered to it led to slovenly work. If a man got an idea into his head that it did not matter how much fuel he used in a blast-furnace, it was not conducive to economic working of the blast-furnace. He thought every endeavour should be made to make the blast-furnace an efficient and self-contained unit to produce pig iron with the smallest quantity of coke. All his life he had taken the greatest interest in the question of dehydrating the blast. The question was of the very greatest importance, not only from the point of view of the saving of fuel, but more particularly from the regularity of the products

produced, and especially was that the case in making basic pig iron in which low silicon was required for open-hearth steel production. He would be interested to know whether, in the event of excess gas not being available, it would be possible to carry out the activation process by by-passing some of the flue gases.

Mr. LEWIS, in reply, thanked the various speakers for the kind way in which they had discussed his paper. Mr. Simons had referred to the ease of operation. There was simply a 20-H.P. motor for driving the activating gas through the plant, and some hand-operated valves. When the experimental stage was past there was no reason why the whole plant should not be looked after by one moderately responsible man, say, a fairly well-trained furnace man.

He desired to point out that the criticisms on pp. 44 and 45 to which reference had been made during the discussion, were not his own; he had merely tried to summarise the criticisms on dry blast that he had read in various places. Mr. Simons mentioned particularly the remark that the expenditure made on the plant might be better spent in other ways; he thought that in nearly all the cases where a Gayley plant was installed it was a fair criticism. More improvement could be obtained by raising the blast temperature 100°C. or 200°C. than could be obtained from dry blast *per se*. Dry blast, together with other improvements, was still in his view a sound investment. He had also tried to make it clear that each case would have to be considered on its own merits. It was necessary for each ironmaster, after taking everything into consideration, including the use of gas for other purposes, such as in the steelworks, and also the assumption that Johnson's theory was sound, to see exactly how his commercial balance-sheet would work out.

Mr. Simons had also mentioned the 10 per cent. saving. He did not in the least wish to overstate the case, but it seemed to be shown that during the wet months of July and August they were getting a 10 per cent. saving as against the normal July and August conditions. He did not claim that they obtained that saving over the whole year, and of course it was the whole year which produced the balance-sheet and the dividends.

He desired to refer next to Mr. Talbot's remarks on the use of gas in steelworks. There were three ways, and three ways only, in which to economise fuel in the blast-furnace, namely, by reducing the quality of the top gases, by reducing the quantity of the top gases, and by reducing the sensible heat of the top gases. Each person using the gas for other purposes must carefully weigh up the possibilities, and determine whether it were better to run the furnaces as gas-producers or to have a separate gas-producer plant. If the blast-furnace were to be run as a gas-producer it was far better to run it as an efficient gas-producer, and that would be attained by keeping a constant moisture in the blast. By means of the dilution door it was possible

to run a perfectly constant moisture content in the blast of, say, $2\frac{1}{2}$ or 3 grains per cu. ft., or anything below the normal conditions, or to arrange to run 2 grains through the winter and 3 or 4 grains through the summer. In that respect there were great possibilities for the use of silica gel for regulating the blast by even those people who did not want dry blast. The lower curve in Fig. 3 was extraordinarily regular. During that period in May, when there were variations from 5 grains to 1.7 grains of moisture in the atmosphere, the moisture in the blast never exceeded 1.2 grains and never went below 0.8 grain; the blast, according to the average day-by-day figure, was running within 0.01 grain of what they were aiming at. He desired to add one comment in regard to Mr. Talbot's remarks. If a blast-furnace were being run as a gas-producer with constant moisture in the blast one would, in addition to getting better general running, obtain a very much improved quality of iron.

Mr. Roberts had mentioned that Gayley's results, which were rather startling at first, had not been maintained. He did not know how far that might be due to his having done what the critics wanted him to do—increase his blast temperature. If he had done so from the first he would not have got the phenomenal results he did, because the saving due to dry blast was very much larger where there was a low critical temperature and a low blast temperature than it was in such conditions as were experienced at Wishaw. Wishaw was one of the worst possible places to try out a dry-blast plant, because there was in the inhospitable climate there a low atmospheric temperature and consequently very low moisture in the atmosphere. He thought it was possible that several of the Gayley plants were stopped because it was found far better to spend the money in other directions and not to pay for their maintenance.

Mr. Henderson had mentioned the many variables that existed. It seemed to him that if one of those variables could be pinned down that was one point gained, and it was then possible to proceed to pin down another one. One of the variables was the size of ore. During one of the last three weeks, owing to a sudden change in the nature of the ore used, the output in his plant had dropped 10 per cent., due to that one variable only. He was very glad to hear Professor Desch's remarks with regard to the reversibility of silica gel; he now felt more confident that the plant would continue to work satisfactorily. In reply to Mr. Barrett, his (the author's) statement that 0.5 grain of moisture in the blast represented about 10 lb. of water per ton of pig was quite correct for Wishaw conditions. That was due to the fact that they were working with a fairly low carbon consumption. The figure would be much larger in places where 35 cwt. of coke per ton of pig iron were used. The 7 tons of coal per day which was required for activation was for a plant of 35,000 cu. ft. which was producing at the moment about 2100 tons of pig iron per week. That was the maximum quantity required only under full summer conditions. Taking that coal

at 10s. per ton, the cost per ton of pig iron was slightly over $2\frac{1}{2}$ d. It was not at the moment costing them anything, because they were not using the whole of their gas.

With regard to the President's suggestion for using waste gases for activation, they had gone very carefully into the question of activation by means of heated air before it was decided that the use of their own gas for that purpose was safe, but it was found that the necessary apparatus, besides being complicated, would add very considerably to the cost of the whole plant. Provided the air could be heated to 640° F. (338° C.) by means of waste gases, the process was feasible, but that was a rather high temperature to attain with their own waste gases.

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ON THE THEORY OF THE BLAST-FURNACE PROCESS.¹

BY DR. FRITZ WÜST (DÜSSELDORF).

IN text-books and proceedings the view is generally held that the reduction of the manganous oxide, silica, and phosphoric acid does not take place until after complete fusion of the carburised iron, and that it then occurs in the neighbourhood of the tuyeres, that is, in the hearth.² According to most investigators, the reduction of these oxides is effected by elementary carbon—that is to say, by so-called direct reduction. In the case of manganous oxide alone, the view is held by Jüptner,³ Wedding,⁴ and Simmersbach,⁵ that reduction can be effected also by carbon monoxide or by so-called indirect reduction.

From the following arguments it will be seen that manganese, silicon, and phosphorus cannot be taken up by the iron in any considerable quantity in the blast-furnace hearth.

The iron trickling down in front of the tuyeres will become burned to a considerable extent, due to the oxygen, the water, and the carbon dioxide present in this oxidising zone. About 15 per cent. of the oxygen of the blast combines with the iron as

¹ Received June 21, 1927.

² Grüner, "Métallurgie du Fer," p. 168. 1862. Bell, "Manufacture of Iron and Steel," p. 165. 1884. Sexton, "An Outline of the Metallurgy of Iron and Steel," pp. 62 and 64. 1902. Ledebur, "Handbuch der Eisenhüttenkunde," vol. ii. p. 218. 1906. Turner, "The Metallurgy of Iron," p. 170. 1908. Hudson, "Iron and Steel," London, 1913. Osann, "Lehrbuch," p. 448. Second edition, 1915. Johnson, *Metallurgical and Chemical Engineering*, 1915, vol. xiii. pp. 636 and 790. Fletcher, *Iron and Coal Trades Review*, 1916, vol. xcii. p. 364. Mathesius, "Lehrbuch," p. 222. 1916. Simmersbach, *Stahl und Eisen*, 1918, vol. xxxviii. p. 136. v. Jüptner, "Hochofentheorie," p. 114. 1921. Forsythe, "Blast-Furnace and the Manufacture of Pig Iron," p. 200. 1922. Stoughton, "The Metallurgy of Iron and Steel." New York, 1923. Davis, *United States Bureau of Mines*, 1923, *Report of Investigations*, 2502; *Iron Age*, 1923, vol. cxii. p. 717. v. Schwarz, "Eisenhüttenkunde," vol. i. p. 85. Bichereaux, "Principes de Sidérurgie," p. 46. 1924. Derclaye, *Revue de Métallurgie, Mémoires*, 1924, vol. xxi. pp. 315, 396, and 450. Brown, *Blast-Furnace and Steel Plant*, 1925, vol. xiii. p. 236. Barr, *Stahl und Eisen*, 1925, vol. xlv. p. 438. Korevaar, "Combustion in the Gas-Producer and Blast-Furnace," p. 124. 1924.

³ *Loc. cit.*

⁴ Wedding, "Lehrbuch," vol. iii. p. 615. 1906.

⁵ Simmersbach, "Eisenindustrie," p. 13. 1906.

it trickles down, causing the formation of very large quantities of ferrous oxide, which are taken up by the slag covering the metal.¹ The slag thenceforth exercises a refining effect on the metal bath, just as in the open-hearth, and since the iron oxide reduced in this way is continuously replaced by fresh formation, any reduction of manganous oxide, silica, and phosphoric acid can only take place if the iron oxide content of the slag reaches an inconsiderable amount dependent on the temperature. Such a condition being scarcely likely to occur, these other elements associated with the pig iron cannot on theoretical grounds be taken up in the hearth below the tuyere level.

The reduction of manganous oxide, silica, and phosphoric acid must accordingly take place above the tuyere level in the furnace, and a well-grounded but hitherto unnoted proof of this conception is furnished by the charcoal blast-furnace. In the older furnaces of this type, with open front, the bosh temperature was not very high, so that the metal sank slowly through the viscous slag, and there always remained a portion suspended in the slag as it ran off. By breaking and washing off the slag, this iron, called "washed iron" (*Wascheisen*), was recovered, and was re-charged into the furnace.

In the year 1885 the author began his practice in blast-furnace work at the ironworks of Wasseraufingen, rendered famous by Faber du Faur. Here there was a charcoal furnace in operation alongside of a coke blast-furnace. An examination of the washed iron showed that it was already a pig iron precisely the same in character as the simultaneously produced pig iron from the furnace, and this fact being in complete opposition to the prevailing view, the author's trustworthiness as an analytical chemist was for a long time thereafter in doubt.

In 1910 the author² examined samples of washed iron and of simultaneously produced pig iron from five charcoal blast-furnaces. The results are given in Table I.

A comparison of the composition of the washed iron with that of the iron run off at about the same time, in any case during the same tapping, reveals the correctness of the theory postulated at the opening of the paper, and indicates with satisfactory clearness

¹ Wüst, *Stahl und Eisen*, 1926, vol. xlv. p. 1213.

² Wüst, *Metallurgie*, 1910, vol. vii. p. 403.

TABLE I.—Analyses of Washed Iron and Pig Iron from Five Charcoal Blast-Furnaces.

Blast-Furnace No.	Sample Mark.	Silicon.			Manganese.			Phosphorus.			Sulphur.		
		Washed Iron.	Pig Iron.	Difference.	Washed Iron.	Pig Iron.	Difference.	Washed Iron.	Pig Iron.	Difference.	Washed Iron.	Pig Iron.	Difference.
I.	J1	% 2.32	% 0.73	% + 1.59	% 1.88	% 1.75	% + 0.13	% 0.17	% 0.11	% + 0.06	% 0.046	% 0.010	% + 0.036
I.	J2	2.00	0.84	+ 1.16	2.05	1.88	+ 0.17	0.15	0.11	+ 0.04	0.030	0.011	+ 0.019
I.	J3	2.02	0.52	+ 1.50	1.78	1.35	+ 0.43	0.16	0.10	+ 0.06	0.030	0.010	+ 0.020
I.	J4	2.14	0.57	+ 1.57	2.02	1.39	+ 0.63	0.16	0.10	+ 0.06	0.032	0.008	+ 0.024
II.	R1	2.11	1.41	+ 0.70	0.75	0.82	— 0.07	0.84	0.67	+ 0.17	0.076	0.042	+ 0.034
II.	R2	2.13	1.43	+ 0.70	0.74	0.80	— 0.06	0.80	0.63	+ 0.17	0.076	0.042	+ 0.034
III.	A1	2.43	1.02	+ 1.41	0.45	0.29	+ 0.16	1.03	0.65	+ 0.38	0.096	0.026	+ 0.070
I.	J5	2.67	1.20	+ 1.47	2.00	1.68	+ 0.32	0.12	0.11	+ 0.01	0.025	0.012	+ 0.013
IV.	Z1	1.96	1.31	+ 0.65	0.64	0.77	— 0.13	0.98	0.73	+ 0.25	0.073	0.031	+ 0.042
V.	B1	1.16	1.25	— 0.09	8.16	5.82	+ 2.35	0.14	0.10	+ 0.04	0.075	0.041	+ 0.034
V.	B2	1.75	0.80	+ 0.95	7.90	5.18	+ 2.72	0.11	0.09	+ 0.02	0.089	0.052	+ 0.037

that the reduction of manganous oxide, silica, and phosphoric acid must take place above the tuyere level. In the great majority of the cases, the washed iron shows a higher content of foreign constituents than the simultaneously produced pig iron. In Fig. 1, where the points of the curves lie above the zero line, this

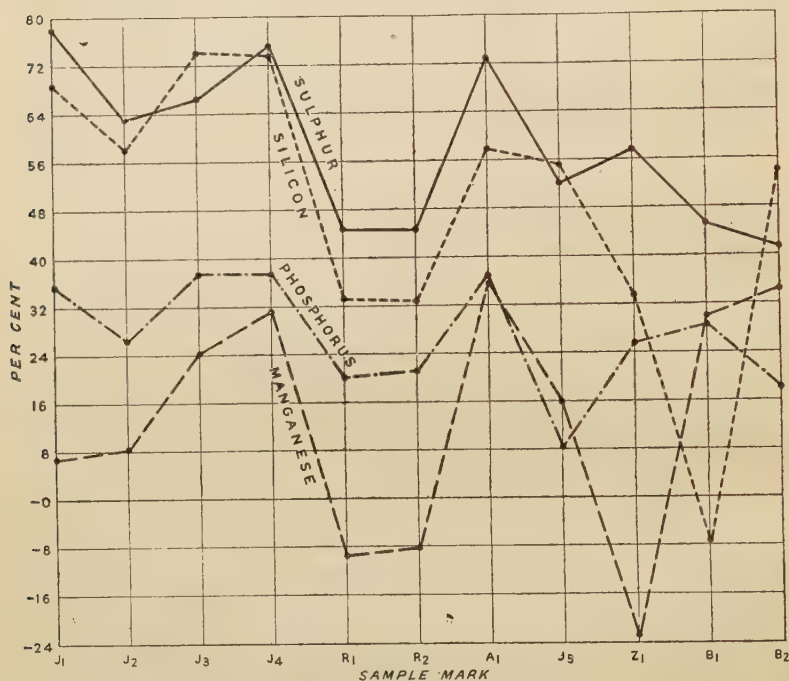


FIG. 1.—Percentage Decrease in Foreign Constituents in the Pig Iron as compared with washed iron from a charcoal blast-furnace.

indicates that the percentages of silicon, manganese, phosphorus, and sulphur in the washed iron are higher than in the pig iron concurrently produced. The points below the zero line show that the opposite is the case.

In Table II. the mean values are given for all the eleven samples of washed iron and pig iron, together with the absolute and percentage differences.

With one exception in the case of silicon and three in the case of manganese (Fig. 1), the percentages of foreign constituents in

the washed iron are all higher than in the concurrently produced iron. The explanation of this decrease as the iron enters the hearth is simple. The iron oxide formed in front of the tuyeres is reduced

TABLE II.

	Washed Iron.	Pig Iron.	Actual Decrease.	Percentage Difference.
	%	%	%	%
Silicon . . .	2.06	1.01	1.05	51.0
Manganese . .	2.58	1.975	0.605	23.4
Phosphorus . .	0.424	0.309	0.115	27.2
Sulphur . . .	0.059	0.026	0.033	56.0

by a portion of the foreign constituents of the pig iron, causing these latter to become re-oxidised and taken up in the slag.

It is of course understood that the carbon of the pig iron also bears its share in the reduction of the iron oxide of the slag. But with the low temperature of the charcoal blast-furnace, the carbon gives way to the silicon, which accounts for the fact that high-silicon pig iron can be produced in the charcoal blast-furnace only with difficulty. In the coke blast-furnace the temperature of the hearth is much higher, and the slag in consequence is more fluid, so that under normal conditions no drops of iron remain suspended in it.

The author is, however, indebted to his friend Dr. Neumark, at Lübeck, for the analyses of some samples of washed iron from a coke blast-furnace, which, during a trial run, was worked with an exceptionally stiff slag. The composition of the washed iron and pig iron samples is given in Table III. In Fig. 2 the percentage reductions of the constituents of the washed iron and those of the pig iron are graphically represented in the same manner as in Fig. 1.

Table IV. shows the difference in the mean composition of the sixteen samples of washed iron and pig iron.

It will be seen that although the differences in the mean composition of the washed iron and pig iron are not of so high an order as in the case of the iron from the five charcoal blast-furnaces, yet they are quite marked. This is due, first, to the lower concentration of the foreign constituents of the pig iron, and, secondly,

TABLE III.—Comparison of Analyses of Washed Iron and Pig Iron from a Coke Blast-Furnace.

Tapping No.	Silicon.			Manganese.			Phosphorus.			Sulphur.			Carbon.		
	Washed Iron.	Pig Iron.	Difference.	Washed Iron.	Pig Iron.	Difference.	Washed Iron.	Pig Iron.	Difference.	Washed Iron.	Pig Iron.	Difference.	Washed Iron.	Pig Iron.	Difference.
5	% 1.10	% 0.82	+ 0.28	% 0.81	% 0.69	+ 0.12	% 0.15	% 0.15	0.0	% 0.048	% 0.041	+ 0.007	% 4.49	% 4.33	+ 0.16
4	0.99	0.62	+ 0.37	0.69	0.70	- 0.01	0.11	0.14	- 0.03	0.022	0.020	+ 0.002	4.99	4.55	+ 0.44
6a	0.58	0.31	+ 0.27	0.66	0.56	+ 0.10	0.12	0.12	0.0	0.030	0.056	- 0.026	6.37	4.21	+ 2.16
2	0.82	0.69	+ 0.13	0.64	...	...	0.15	...	...	0.043	0.032	+ 0.011	4.82	4.55	+ 0.27
6b	0.99	0.62	+ 0.37	0.71	0.71	0.0	0.16	0.14	+ 0.02	0.025	0.038	- 0.013	4.43	4.57	- 0.14
1	0.98	0.70	+ 0.28	0.75	0.69	+ 0.06	0.15	0.16	- 0.01	0.025	0.040	- 0.015	4.22	4.70	- 0.48
2b	0.78	0.82	- 0.04	0.65	0.64	+ 0.01	0.10	0.10	0.0	0.035	0.046	- 0.011	4.66	4.54	+ 0.12
3	1.17	0.75	+ 0.42	0.67	0.72	- 0.05	0.14	0.10	+ 0.04	0.035	0.049	- 0.014	4.61	4.45	+ 0.16
5b	0.56	0.56	0.0	0.73	0.65	+ 0.08	0.15	0.15	0.0	0.060	0.065	- 0.005	4.13	4.38	- 0.25
2c	0.68	0.73	- 0.05	0.68	0.56	+ 0.12	0.16	0.15	+ 0.01	0.032	0.025	+ 0.007	3.88	4.88	- 1.00
4b	0.93	0.89	+ 0.04	0.60	0.60	0.0	0.16	0.17	- 0.01	0.024	0.029	- 0.005	4.01	4.49	- 0.48
5c	0.80	0.66	+ 0.14	0.88	0.71	+ 0.17	0.114	0.105	+ 0.009	0.020	0.029	- 0.009	3.53	4.58	- 1.05
7	0.93	0.79	+ 0.14	0.76	0.68	+ 0.08	0.103	0.106	- 0.003	0.020	0.020	0.0	4.19	4.54	- 0.35
1b	1.39	1.42	- 0.03	0.74	0.68	+ 0.06	0.12	0.13	- 0.01	0.025	0.027	- 0.002	4.65	4.53	+ 0.12
2d	1.67	1.10	+ 0.57	0.73	0.67	+ 0.06	0.14	0.14	0.0	0.030	0.020	+ 0.010	4.58	4.58	0.0
3b	1.01	0.75	+ 0.26	0.74	0.63	+ 0.11	0.14	0.14	0.0	0.041	0.043	- 0.002	4.29	4.29	0.0

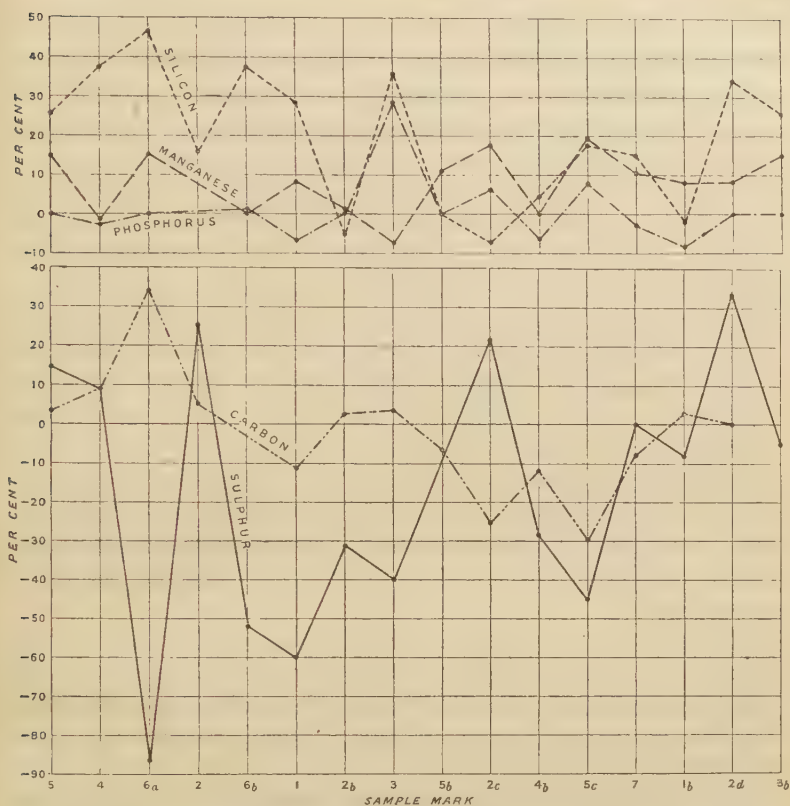


FIG. 2.—Percentage Decrease in Foreign Constituents in the Pig Iron as compared with washed iron from a coke blast-furnace.

TABLE IV.

	Washed Iron.	Pig Iron.	Actual Difference.	Percentage Difference.
	%	%	%	%
Silicon . . .	0.945	0.747	+ 0.198	+ 20.8
Manganese . . .	0.720	0.618	+ 0.102	+ 14.2
Phosphorus . . .	0.134	0.133	+ 0.001	+ 0.75
Sulphur . . .	0.0322	0.0360	- 0.0038	- 11.8
Carbon . . .	4.49	4.50	- 0.01	- 0.22

to the higher bosh temperature of the coke blast-furnace, whereby the carbon has the leading share in the reduction of the iron oxide formed in front of the tuyeres.

There might exist the possibility that during the retention of the washed iron in the slag, the silicon, manganese, and phosphorus are reduced out of the slag by the carbide carbon of the iron. This conception is, however, negatived by the fact that, so long as iron oxide is present in the slag in considerable quantity, a reduction of the above-mentioned oxides cannot take place.

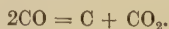
Therefore, the hitherto accepted theory, that the carbide carbon of the liquid pig iron reduces manganous oxide, silica, and phosphoric acid out of the slag, is untenable.

The carburised iron, which on account of its high carbide content has a high melting point, becomes fused at only quite a short distance above the tuyere level and then trickles down between the lumps of coke into the hearth. The time required to run through this space is too short to permit of any reaction on a considerable scale. Moreover, the slag trickling down at the same time as the iron is as a rule spatially separated from the iron, so that any reduction or taking up of foreign constituents during this period of the sinking down of the iron is quite out of the question.

One is therefore forced to the conclusion that not only the carbon but all the foreign constituents of the iron are taken up as aggregates in solid form—in fact, by way of cementation—and that the pig iron on becoming fused is already mainly in its final condition.

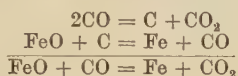
The carbon of the fuel probably plays only a very small part in the formation of the pig iron, since the points of contact between ore and fuel are too few to produce any extensive effect.

Now, it has long been known, through the investigations of Sir Lowthian Bell, Ledebur, and others, that carbon monoxide in the presence of so-called contact materials, such as iron oxide, separates into elementary carbon and carbon dioxide, according to the equation,

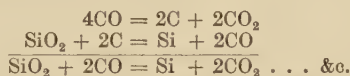


Now in the temperature range from 850° to 350° C., the carbon not only deposits on the surface of the ore, but, in the case of porous ores permeable to gas, it penetrates in such sufficient quantity as to make up in six to eight hours a considerable proportion of the weight of the ore. This finely divided carbon is in close contact with the constituents of the ore. Due to its finely

divided state, it is extremely reactive, and thus promotes the work of reduction by the carbon monoxide until the last remnants of iron oxide are reduced. Part of this carbon sinks down with the reduced ore to the lower zones of the furnace, where with the iron it forms carbide and reduces at the corresponding temperature the manganous oxide, silica, and phosphoric acid, and the elements on being set free are immediately taken up by the iron present. The dissociation of the carbon monoxide is a strongly exothermic reaction, and by the reaction $2\text{CO} = \text{C} + \text{CO}_2$ there are set free 38,960 kg.-cals. By coupling this dissociation process with that of direct reduction the following equation is obtained :



From this it will be seen that thermo-technically the reaction proceeds according to the indirect reduction, which also is in agreement with the following equation for silicon, manganese, and phosphorus :



That is to say, these elements also are thermo-technically reduced only by carbon monoxide.

It is to be borne in mind, however, that the process of the dissociation of the carbon monoxide and of direct reduction go on in quite different zones of the blast-furnace. Therefore the system as a whole is one of indirect reduction, while in the lower part of the furnace the consumption of heat is required for the direct reduction of manganous oxide, silica, and phosphoric acid.

Thus the dissociation of the carbon monoxide, which is regarded by many blast-furnace men as an unfavourable condition, is on the contrary an essential requisite for economical working. Since the dissociation is considerable only at a temperature below 500°C ., a low top temperature is desirable in order to get the full advantage of it. The low temperature of the top gases obtained by heating the blast enables the separation of carbon in large quantities, and herein lies a hitherto unrecognised essentially favourable effect of the hot-blast.

Simultaneously with the evolution of heat which accompanies

the dissociation of the carbon monoxide, a remarkable delay in the fall of the temperature within the shaft takes place, which permits the indirect reduction to take its course more fully.

The investigations of Levin and Niedt¹ show that in a blast-furnace 18 m. (60 ft.) high, the temperature between heights of 4.6 m. (15 ft.) up to 13.9 m. (45½ ft.) above the tuyere level falls from about 800° to about 700°—that is, the gases are able to effect indirect reduction throughout a height of 9 m., or, say, half the height of the furnace.

It then becomes explicable why those ores which are interspersed with fine quartz particles are so particularly suitable for the production of high-silicon pig iron, this being the most favourable condition under which the finely divided carbon can exercise its reducing effect. If, as has been hitherto assumed, a reduction of the silicon from the slag takes place, then the extent to which this happens would be entirely independent of the petrographic quality of the ore.

The foregoing theoretical considerations have been fully confirmed by practical tests. By the kindness of the Notgemeinschaft der Deutschen Wissenschaft, the author has been enabled to investigate this new theory by means of experiments, which were carried out by Dr. H. H. Meyer in the Iron Research Institute (Düsseldorf). The reducing agents employed were hydrogen, carbon monoxide, and elementary carbon in a temperature range of 800° to 1200° C., and as basis were used silica, manganous oxide, and phosphoric acid, the latter in the form of basic slag. After reduction, the quantity of phosphorus, silicon, and manganese taken up by the iron was determined.² A portion of the results of the investigation are summarised in Table V.³ In none of the tests were any fusion and scarcely any sintering observable. The last column of the table shows the kind of iron employed. The electrolytic iron was in the form of prismatic pieces; after the tests with manganese and phosphorus a 0.5 mm. thick layer, and after that with silicon a 1 mm. thick layer, was removed and analysed.

¹ Levin and Niedt, *Metallurgie*, 1911, vol. viii. p. 515.

² Oberhoffer and Heger have previously proved the possibility of the cementation of iron by silicon and silica. *Stahl und Eisen*, 1923, vol. xliii. p. 1474.

³ The complete results will be published in *Mitteilungen aus dem Kaiser-Wilhelm-Institut für Eisenforschung*.

The tests with hydrogen showed that manganous oxide alone was reducible by hydrogen, while phosphoric acid and silica remained unaffected, as may be seen from the tests Nos. 2, 5, and 58 in Table V.

TABLE V.

Test No.	Reducing Agent.	Temperature. ° C.	Time. Hrs.	Analysis.	Kind of Iron.
2	H ₂	1100	7 $\frac{1}{4}$	8% Mn	Electrolytic iron
5	H ₂	1150	9	0.07% P	"
58	H ₂	1200	5	0.03% Si	"
51	CO	1150	5	3.80% Mn	Floral wire
59	CO	1200	5	0.27% P	"
59	CO	1200	5	0.04% Si	"
32	C	1100	4	5% Mn	"
55	C	1170	5	7.97% P	"
57	C	1170	5	2.55% Si	"
21	C	1100	4	1.45% Mn	Electrolytic iron
13	C	1150	4	1.44% P	"
56	C	1170	5	1.32% Si	"

In using carbon monoxide as reducing agent care must be taken to avoid the separation of carbon, which takes place below 1000° C. On this account the test-pieces were not placed in the furnace until the temperature for the experiment had been reached. As will be seen from Table V., manganous oxide is likewise reducible by carbon monoxide, and so apparently is phosphoric acid according to the analysis of test 59. The floral wire used contained originally 0.11 per cent. phosphorus, and therefore 0.16 per cent. phosphorus must have been taken up by reduction. A sample of the wire after annealing for five hours at 1200° C. in carbon monoxide was found to contain 0.32 per cent. carbon, the original carbon having been 0.04 per cent. At these temperatures the carbon monoxide reacts with the iron, forming carbide, and it is probable that this carbon exercises a reducing action on the phosphoric acid, while the silica is not affected.

The tests with solid carbon resulted in the reduction of all three oxides while in the solid state. The oxides were mixed with coal and showed no sign of sintering. On comparing tests 2 and 21 it will be noted that hydrogen has a stronger reducing effect than carbon on manganous oxide. The lower reducing effect of

carbon is probably due to the formation of manganese carbide, which impedes the diffusion of the manganese into the iron.

The temperatures at which the reduction of the oxides by solid carbon in the presence of iron started were determined as follows: Manganous oxide at 900° , phosphoric acid at 1050° , and silica at 1100° C. That is, the reduction of the oxides takes place at a temperature below the melting point of pig iron, and not, as is generally assumed, after it reaches the liquid state.

All reactions in the solid state, such as have frequently formed the subject of investigation by Tammann and Hedvall,¹ depend, of course, very largely on the intimate mixing, the contact, and the area of the surfaces. The influence of the surface is clearly evident in the reduction tests with solid carbon, as recorded in Table V. In those where floral wire was used—that is, where the surface was larger—the reduction is much stronger than with the electrolytic iron. The floral wire after four hours' annealing at 1100° contained 5 per cent. manganese, while the electrolytic iron showed only 1.45 per cent. manganese in the 0.5 mm. thick outer layer under the same conditions.

In the blast-furnace the reduction of the iron oxides is about complete when the burden has reached a temperature of 800° . The next lower zone down to the melting zone is often regarded as a zone of chemical inactivity. The results of the reduction tests have shown that this view is not correct, but that shortly after the reduction of the iron oxide is ended and before the burden sinks down into the melting zone, the reduction of the manganous oxide and of the other oxides sets in.

The conditions for reduction in the blast-furnace are far more favourable than in the tests as carried out. The iron is present in the blast-furnace as iron sponge, and being intimately mixed with the oxides it presents the largest possible superficial area to the accompanying elements diffusing into it.

SUMMARY.

In the oxidising gas phase in front of the tuyeres oxidation of the iron occurs, whereby the slag becomes charged with ferrous

¹ Tammann, *Zeitschrift für anorganische Chemie*, 1925, vol. cxlix. pp. 21–98; Hedvall, *ibid.*, 1916, vol. xcviii. p. 57; 1924, vol. cxxviii. p. 57.

oxide. Therefore no reduction of manganous oxide, silica, and phosphoric acid from the slag can take place, for the reason that silicon, phosphorus, and manganese would immediately become re-oxidised by the iron oxide. The reduction of these oxides must therefore be effected above the tuyere level. Analyses of washed iron from five charcoal blast-furnaces and one coke blast-furnace prove this. Tests with silica, phosphoric acid, and manganous oxide resulted in the reduction of these oxides with elementary carbon in the presence of iron. Silicon, manganese, and phosphorus diffuse into the iron before melting in the same way as carbon, so that the iron is actually formed into pig iron before it melts. Hydrogen and carbon monoxide reduce only manganous oxide. For the reduction in the blast-furnace the principal agent is the carbon formed according to the equation $2\text{CO} = \text{CO}_2 + \text{C}$, which penetrates into the pores of the ore, thus specially tending to promote reduction.

CORRESPONDENCE.

Mr. S. P. KINNEY (Metallurgist, U.S. Bureau of Mines, Washington) presented the following communication ¹ in discussion of Dr. F. Wüst's paper "On the Theory of the Blast-Furnace Process."

FINDINGS OF THE U.S. BUREAU OF MINES.

In 1924 the Bureau of Mines made a study of the composition of the gases on a series of planes ² between the stockline and tuyere level of a Southern foundry furnace making 300 tons of iron a day. The composition of materials from a number of planes was also studied, and the results of this later phase of the investigation were published ³ in 1926. In brief, the findings were as follows :

1. Results of sampling stock and gas in the upper part of the blast-furnace stack show that 80 to 85 per cent. of the iron in the burden is reduced to the metallic form by the time it has reached a plane 19½ ft. above the tuyere level.

2. It has been shown that metal, in the form of sponge iron, has taken up, or is in intimate contact with, considerable quantities of carbon, phosphorus, manganese, and silicon by the time it has reached a plane 19½ ft. above the tuyere level and 8 ft. above the top of the bosh.

3. About 87 per cent. of the silicon entering the metal is taken up while the metal is in the bosh above a plane 27 in. above the centre line of the tuyeres, and the remaining 13 per cent. is taken up between the above point and the crucible.

4. It has been shown that the silica in the coke ash has little effect on the amount of silicon in the metal, because the metal has obtained most of its silicon before it reaches the tuyere level.

5. Approximately one-third of the manganese enters the metal, or is very closely associated with it, above a plane 19½ ft. above the tuyere level. The manganese content of fifteen casts was 0.53 per cent. ; metal samples from the plane 19½ ft. above the tuyere level and from the plane 27 in. above the tuyeres contained 0.22 and 1.10 per cent. Mn, respectively. Between the two above-mentioned planes considerable manganese is taken up, part of which is probably oxidised later in the tuyere zone.

6. All of the phosphorus has entered the metal by the time the metal has reached a plane 27 in. above the tuyeres. Approximately one-half

¹ Presented by permission of the Director, U.S. Bureau of Mines.

² S. P. Kinney, P. H. Royster, and T. L. Joseph, "Iron Blast-Furnace Reactions," *U.S. Bureau of Mines Technical Paper*, No. 391, 1926, 65 pp.

³ S. P. Kinney, "Composition of Materials from Various Elevations in an Iron Blast-Furnace," *U.S. Bureau of Mines Technical Paper*, No. 397, 1926, 22 pp.

of the phosphorus has entered or become intimately combined with the metal at the plane $19\frac{1}{4}$ ft. above the tuyere.

7. More than one-third of the carbon has been taken up by the metal by the time it reaches the plane $19\frac{1}{4}$ ft. above the tuyeres ; the remainder is taken up while the metal is in the bosh of the furnace and before it reaches the level of the tuyeres.

8. The tolerant limit on sulphur is 0.05 per cent. At the planes $19\frac{1}{4}$ ft., 27 in., and the tuyere plane, the metal contained approximately 140, 360, and 140 per cent., respectively, of the tolerant limit. At the plane $19\frac{1}{4}$ ft. above the tuyeres the metal had taken up 3.33 per cent. of the sulphur which had been charged into the furnace, whereas at the plane 27 in. above the tuyeres the metal had taken up 12.0 per cent. of the available sulphur. The results indicate the ease with which the sulphur is absorbed in the upper part of the furnace ; they also readily show that the metal continues to take up sulphur while it is in the bosh of the furnace, probably because that part of the metal is not covered with slag, and is therefore subject to contamination with sulphur produced from the combustion of coke at the tuyere level.

9. Determination of forms of sulphur in coke samples at the plane $19\frac{1}{4}$ ft. above the tuyere level shows that approximately 25 per cent. of the sulphur has been removed from the coke by the time it reaches this plane, and the sulphur which has been removed is that which existed in the coke as ferrous sulphide and free sulphur. About half of the ferrous sulphide and free sulphur has been removed at the plane $19\frac{1}{4}$ ft. above the tuyeres.

10. Analyses of samples of limestone taken from the plane $19\frac{1}{4}$ ft. above the tuyeres show that the lime has taken up 0.77 per cent. sulphur, which is approximately 26 per cent. of the available sulphur charged. Coke at this point has lost 25 per cent. of its sulphur, and the metal has taken up 3.33 per cent. of the available sulphur. Preferential absorption of sulphur by lime in the upper part of the furnace is demonstrated by these results.

DISCUSSION OF BUREAU OF MINES INVESTIGATION.

Silicon.—The work reported by the Bureau of Mines indicates that 87.4 per cent. of the silicon has been taken up by the metal at a plane 27 in. above the tuyeres, and 98.3 per cent. has been acquired by the time the metal has reached the tuyere plane. Comparative results are as follows :

<i>Distance above Tuyeres.</i>	<i>Silicon.</i>	
	<i>In Metal.</i>	<i>At Cast.</i>
	%	%
$19\frac{1}{4}$ feet	0.42	1.97
27 in.	2.55	2.92
Tuyere level	2.95	3.00

Manganese.—The comparative results for manganese have already been summarised, but it is again pointed out that a portion of the

manganese was lost in the tuyere zone, which would indicate oxidation of manganese in this zone.

Sulphur.—The sulphur at the three planes mentioned above was found to be 0·070, 0·179, and 0·072 per cent., respectively, while the casts were 0·028, 0·041, and 0·045 per cent.

Sample from another Furnace.

The comparative analyses of metal taken at a tuyere and at cast are as follows :

Constituent.	Samples from :	
	Tuyere Plane.	Cast.
	%	%
Carbon	3·67	...
Manganese	0·80	0·81
Silicon	2·50	1·47
Sulphur	0·11	0·064
Phosphorus	0·17	0·126

In these samples it will be noted that most of the metalloids have entered the metal before the tuyere level has been reached. The manganese from the tuyere, as compared with the cast, is virtually constant, whereas the silicon has been oxidised, as is evidenced by the reduction of silicon in the sample at cast. The high sulphur, 0·11 per cent., in the metal at the tuyere is representative of many other samples which the writer has obtained. The fact that 0·064 per cent. sulphur is found in the metal at cast is direct evidence of the fact that sulphur reduction takes place below the tuyeres, while the metal is passing through the layer of slag. This result would indicate that the reduction of sulphur takes place rapidly, and the comparatively thin layer of slag is very efficient in this respect.

Slag Samples.

In the following table a number of samples of slag are reported, and these are compared with samples which were taken from the tuyere plane and the centre of the hearth :

<i>Source.</i>	<i>Constituents.</i>						
	SiO ₂ .	Al ₂ O ₃ .	CaO.	MgO.	S.	FeO.	MnO.
Tuyere ¹	36·55	15·02	31·65	12·81	0·77	1·89	0·91
Tuyere	38·60	17·88	30·40	11·06	1·72	1·40	...
Cinder notch	36·80	17·20	44·04	...	1·46	1·20	...

Only a few representative samples are reported here, and it is pointed out that the FeO in the slag samples is less than 2 per cent. Samples taken at the plane 27 in. above the tuyere had an iron content of 0·83 per cent., as compared with the slag at the cinder notch, which contained 0·49 per cent. Two other samples contained 0·76 and

¹ Taken in sample tube from centre of hearth. Sample light in colour.

1.38 per cent. FeO, whereas samples at the plane 19½ ft. above the tuyere carried FeO contents of 4.00 and 4.06 per cent. The results indicate that the FeO content of the slags is not high, especially in the slags taken from the vicinity of the tuyere and in the centre of the hearth.

In taking gas samples at the tuyere level of the iron blast-furnaces it has often been noticed that the slag, which at times flows into the gas line and solidifies, is light in colour, also that the iron content of these slags is low. The hearths of seventeen furnaces have been explored, and in general it might be said that the slags contain little iron, and are grey or light in colour.

Oxidation of Iron at the Tuyeres.

Dr. Wüst makes this statement in the beginning of his paper: "About 15 per cent. of the oxygen of the blast combines with the iron as it trickles down, causing the formation of large quantities of ferrous oxide, which are taken up by the slag covering the metal."

A number of calculations might be made on the basis of this statement. For example, if a furnace be considered which is producing 750 tons of iron per day, and consuming 50,000 cu. ft. of air per minute, and producing a slag volume of 1000 lb. per ton of iron, the following conditions are attained:

Iron per minute	.	.	.	.	1,044 lb.
Slag	"	.	.	.	522 lb.
Air	"	.	.	.	50,000 cu. ft.

The oxygen consumed is 10,450 cu. ft. per minute, or approximately 935 lb. at 32° F. and 30 in. of mercury; 15 per cent. of the oxygen consumed is 140 lb. per minute, and if this is consumed in the oxidation of iron to FeO in front of the tuyeres, 630 lb. of FeO would be produced each minute. This would enter the slag, or the slag should contain $630/522 = 121$ per cent. FeO. This might be considered in another light, that is, the 630 lb. of FeO might be added to the 522 lb. of slag, as the FeO is subsequently reduced from the slag. We would then have $630/1152 = 54.5$ per cent. FeO in the slag. In comparison to this value it is pointed out that slag samples removed from the centre of the hearth and the vicinity of the tuyeres show less than 2.0 per cent. FeO. It is, of course, realised that the iron oxide added to the slag might be rapidly reduced, but, in turn, it is pointed out that, as the process is a continuous one, it should be possible to recover samples from the hearth plane that would approach this calculated value. On the basis of samples which the Bureau of Mines has obtained from the tuyere plane and on the above calculation, the writer cannot agree that 15 per cent. of the blast is consumed in the oxidation of iron at the tuyeres.

Oxidation of Manganese, Silicon, and Carbon.

Analyses of various samples of iron for manganese, silicon, and carbon, above and at the tuyere level, at the cinder and iron notch, indicate that oxidation of these elements has taken place at the tuyeres. On the basis of these results the blast-furnace tuyere, or combustion zone, might be compared to a Bessemer converter. In the converter, manganese, silicon, carbon, and iron are oxidised, and oxygen is consumed in each case. The oxidation of manganese, silicon, and carbon takes place approximately in the order given. The various stages are accompanied by the oxidation of iron. At the beginning of the blow, FeO and MnO probably appear simultaneously.

As oxidation takes place at the tuyeres, the writer cannot but believe that manganese, silicon, and carbon, as well as iron, are oxidised. The portion of the blast consumed in oxidation is not selective in action—that is to say, it will not oxidise iron only. The oxidation is divided between manganese, silicon, carbon, and alkali cyanides. As the slag in the tuyere zone of a furnace working normally contains less than 2 per cent. FeO, 15 per cent. of the oxygen entering the furnace cannot be consumed in oxidation of iron.

It is believed that the accumulation of comparatively large quantities of manganese, silicon, and carbon in the metal, while in the bosh of the furnace, produces a resultant beneficial effect on the iron, in that the metal is protected to a certain extent from oxidation while passing through that portion of the combustion zone where free oxygen exists.

Foundry Irons.

As these reactions take place in both large and small furnaces alike, there should be little difference in the quality of foundry irons from furnaces of large or small capacity. The fact that a furnace is producing 750 tons per day, as against a furnace producing 300 tons a day, should make little difference in the quality of the iron produced, in so far as oxidation is concerned.

CONCLUSIONS.

1. In general, it might be said that the two papers (by Dr. Wüst and by the writer) are largely in agreement. Both investigations, which were independent of each other, plainly indicate that the greater part of the metalloids have been acquired by the metal by the time the tuyere level is reached.

2. Analyses of samples of slag from the tuyere zone and from the centre of the hearth indicate less than 2.00 per cent. iron oxide content.

3. If 15 per cent. of the oxygen consumed were used in oxidation of iron at the combustion zone, the slag should contain about 54.5 per cent. of iron oxide.

4. Iron at cast shows a reduction in manganese, silicon, and carbon in comparison with samples taken from the tuyere plane.

5. As the iron from the cast shows a decrease in manganese, silicon, and carbon, these elements are oxidised at the tuyere. It is pointed out that the mechanics of this oxidation are similar to those taking place in the Bessemer converter.

6. As manganese, silicon, and carbon are oxidised at the tuyere zone simultaneously with iron, in the order named, a certain beneficial effect is exercised on the iron, since the presence and the oxidation of these metalloids exercise a protective effect and retard the oxidation of iron.

7. As oxidation of the metalloids takes place in a large or small hearth, the quality of the iron from either furnace (large or small) should be similar with respect to the presence of oxidised iron.

IVAR BOHM (Royal Technical College, Stockholm) wrote: In his interesting paper regarding the reduction of silicon, manganese, and phosphorus in the blast-furnace, Dr. Wüst has proved by direct experiments that these elements may, when iron is simultaneously present, be reduced and absorbed by the iron in considerable quantities, even at a temperature below the melting point of pig iron. On the basis of these facts, and as Dr. Wüst considers that no reduction of these constituents can occur while the pig iron and slag are dropping down through the mass of coke above the level of the tuyeres, as the drops there run separately from each other, and, furthermore, as, according to Dr. Wüst, the pig iron on passing through the slag bath and in the surface between slag and pig iron is refined by the formation of ferrous oxide in front of the tuyeres during the oxidation of the pig iron, the percentages of silicon, manganese, and phosphorus in the pig iron must have been greater than that of the pig iron tapped. Consequently, when the drops of pig iron start melting off from the solid reduced ore, they must have about the same composition as the tapped pig iron.

The question as to how pig iron is formed and its variation in the blast-furnace hearth has during recent years excited an increasing interest, since there is good reason to believe that it is just this part of the furnace which is of fundamental importance for the quality of the pig iron, and consequently for that of the resulting steel. The most dangerous zone which the iron has to pass during its production is just the tuyere level, where the pig iron is subjected to the oxidation of the oxygen of the blast, and where the temperature is high. The degree of the refining in front of the tuyeres is evidently of no great importance as regards the quality, as the pig iron in the subsequent steel process is strongly oxidised. Apparently it is the highest temperature to which the pig iron is heated that determines its quality.

In recent years various investigations have been carried out in Sweden to ascertain and to examine the above-mentioned conditions,

and some experiments derived from those investigations are now advanced for comparison with Dr. Wüst's experimental results. In this comparison it must be remarked, however, that my values relate to the conditions prevailing in a charcoal furnace. Thus, the fuel of the Swedish furnaces burns more easily than coke, the average temperature in the hearth is lower than that in a coke furnace, the charge is more difficult to reduce, and the slag has a higher silicon content (SiO_2 , 45-55 per cent.).

At the testing furnace of Jernkontoret ("Iron Masters' Association") (6 m. in height, capacity 7.8 cu. m.), I carried out in 1924 some investigations in order to study the formation of slag and pig iron. Samples of the charge were taken from the furnace at different levels, and were tested chemically and mineralogically. From those investigations, which were published in *Jernkontorets Annaler*, 1927, pp. 145-208, the following conclusions were adduced: When a self-fluxing ore which was difficult to reduce was smelted, the iron sponge at a height of 1.5 m. above the tuyeres contained 0.04 per cent. of Mn, and 0.12 per cent. at a height of 0.3 m. The pig iron obtained contained 0.06 per cent. of Mn.

On smelting a charge of quartziferous ore and limestone, the percentage of manganese in the drops of pig iron increased from 0.08 per cent. at 2 m. above the tuyere level to 0.15 per cent. at the tuyere level; the percentage of silicon in the drops lay between 0.25 and 0.35 per cent. The sponge from the 2 m. level contained C 0.31 per cent. and Mn 0.06 per cent. The tapped pig iron contained Mn 0.39 per cent. and Si 0.94 per cent. As no carbon precipitation worth mentioning could be observed in those ores (max. C 0.40 per cent., 3.3 m. above tuyeres at 650° C.), I inferred that the reduction of silicon, as well as that of manganese and phosphorus, was brought about by the carbon which was present in the iron carburised by the gas. As a matter of fact, the carburised iron in the ore is in direct contact with the quartz and other minerals. When the slag was completely formed, which occurred first at the tuyere level, it contained only about 50 per cent. of SiO_2 , and consequently the reduction of silicon was impeded. However, the samples taken proved that the drops of pig iron do not separate from the acid, tough and partly slagged ore at the moment when the pig iron reaches its melting point, but the drops follow the slag particles until the pig iron, owing to its increased fluidity, can detach itself. The reaction between the solid mass of slag and the pig-iron drops, therefore, continues after the melting point of the iron is passed. In the zone immediately above the tuyere, where the temperature is highest, the drops of pig iron and slag have separated completely, and the reaction between them is interrupted. One circumstance—at any rate as regards charcoal working—that may cause an increase in the time of reduction between the drops of pig iron and those of slag, is that some slag and pig iron is sucked into the crevices in the charcoal and thus passes down the hearth with the velocity of the fuel mass. All charcoal

samples taken from the hearth contained smaller or larger drops of pig iron and slag, which were molten together in the crevices.

It is evident from the above that one portion of the silicon and manganese of the pig iron is taken up by the iron before it is molten, and that another portion is taken up by the pig-iron drops between the point where the pig iron reaches its melting point and the level where the slag and the iron separate. When the pig iron passes the tuyere level it is therefore alloyed with carbon, silicon, and manganese as well as with phosphorus and sulphur. Kinney's investigations (*Bureau of Mines Technologic Paper, No. 397, 1926*) confirm that conception.

In the autumn of 1926 I made some attempts to study the reactions in the hearth of a large Swedish charcoal furnace, where the daily output was 25 tons of Lancashire pig iron. The slag contained approximately 48 per cent. of SiO_2 , 0.35 per cent. of MnO , and 2.50 per cent. of FeO . Three samples of the pig iron were taken at each tapping—namely, at the beginning, at the middle, and at the end of the tapping; in addition, the temperatures of the pig iron and slag were taken during the tapping. The temperature of the pig iron rose steadily during the tapping, and the difference in temperature between the commencement and the end of the tapping varied between 50° and 80°C . The temperature of the hottest slag during a tap was between 50 and 60°C . higher than that of the pig iron tapped immediately afterwards. The percentages of carbon and silicon in the pig iron rose towards the close of the tapping. One tapping had Si 0.57 per cent. and C 4.15 per cent. in the first half, and towards the end Si 0.72 per cent. and C 4.31 per cent. That regularity in the varying percentages of carbon and silicon was observed in all the tappings.

The increase in the percentage of silicon depends on the fact that the silica in the slag bath is reduced by the carbon in the pig iron and by the charcoal, which penetrates the slag and passes down through the pig iron. After tapping, the layers of iron and slag are at a greater distance from the tuyeres, and the reaction surface between the iron and slag is at a lower temperature. As more iron is accumulated on the hearth, the reaction surface will approach more closely to the hot zone of combustion, the temperature will become higher, and the silicon reduction increases. As will be seen from the figures, a certain absorption of carbon takes place also in the pig-iron bath, on account of the charcoal penetrating through the slag.

It will be seen from the following figures from another Swedish blast-furnace that manganese and silicon may be reduced in the reduction surface between the iron and the slag.

The samples of the pig-iron drops were in this case taken with a ladle introduced through a tuyere *while the blast was shut off*. The output of the furnace was about 25 tons of O.-H. pig iron per day, and the slag contained about 45 per cent. of SiO_2 , 1.5 per cent. of MnO , and 1 per cent. of FeO . The blast temperature was 350° to 400°C .

Experiment No. I.

Drops of Pig Iron at 11 and 15 o'clock. Mean Value.		Pig Iron tapped at 16 o'clock.			
		Commencement.	Middle.	Close.	Mean Value.
Carbon	4.36	4.29	4.42	4.40	4.33
Manganese	0.47	1.03	1.05	1.09	1.06
Silicon	0.19	1.13	1.15	1.18	1.15
Phosphorus	0.017	0.017	0.017	0.017	0.017
Sulphur	0.016	0.008	0.007	0.007	0.007

Experiment No. II.

Drops of Pig Iron at 10 o'clock.		Pig Iron tapped at 10 o'clock. Mean Value.
Carbon	4.76	4.38
Manganese	0.53	0.90
Silicon	0.41	1.11

According to Experiment No. I., 56 per cent. Mn and 83.5 per cent. Si was reduced from the slag layer; according to Experiment No. II., 41 per cent. Mn and 63 per cent. Si.

That silicon and manganese are taken up by the pig iron previous to its accumulation on the bottom of the hearth also appears from the fact that one and the same charge of ores gives a pig iron with varying percentages of silicon and manganese, simply by distributing the ores differently when charging. As is well known, the Swedish blast-furnaces are provided with charging devices, which allow of an accurate distribution of the ore in the top of the furnace. The greater portion of the ore is generally placed in a circle around the wall, the rest being distributed equally above the charcoal in the centre of the furnace. For a long time it has been known that if, for instance, a quartziferous ore be charged in the centre, and an ore containing manganese along the furnace wall, a pig iron will result which contains more silicon and less manganese than if the manganiferous ore be placed in the centre and quartziferous ore along the periphery. That difference will be seen from Tholander's values (*Jernkontorets Annaler*, 1891, p. 180). (See table, p. 87.)

When the quartziferous ore is placed by itself in the centre of the charge that portion becomes more acid, the slagging of the quartz is delayed, and the reduced iron and the drops of pig iron are given a longer time to react with the acid material. If, on the other hand, in an other-

wise unchanged charge, the manganiferous ore be placed together with limestone in the centre, and quartziferous ore along the wall, more manganese will be reduced from the charge because of the greater

Experiment No.	Quartziferous Ore in the Centre, Manganiferous Ore around the Wall.		Quartziferous Ore around the Wall, Manganiferous Ore in the Centre.	
	Percentage in Pig Iron of :			
I.	Si. 2.32	Mn. 1.10	Si. ...	Mn. ...
II.	2.18	1.10	...	...
III.	...	...	1.47	1.44
IV.	...	...	1.86	1.41

basicity of the slag formed by the manganiferous ore and the limestone, which facilitates the reduction of manganese.

That the composition of the pig iron is influenced by the speed of the slagging of ores is also apparent from the fact that on smelting an ore, the gangue of which is of the same composition as the final slag (self-fluxing ore), a lower percentage of silicon will be obtained in the pig iron than if the charge consisted of quartziferous ore and limestone.

The instances cited may be sufficient to show that the reduction of silicon and manganese takes place already in the solid iron as well as in the drops of iron and slag sinking down through the upper part of the hearth, and also at the boundary surface between the layers of slag and pig iron at the bottom of the furnace.

Dr. Wüst replied as follows : Mr. Kinney confirms in all essentials my opinions on the production of pig iron in the blast-furnace expressed in earlier papers.¹ In his investigations in the Bureau of Mines' experimental blast-furnace—of which experiments I first became aware after submitting my own paper in June of this year through their publication in the August, 1927, number of *Blast-Furnace and Steel Plant*—he shows that the greater part of the silicon, manganese, and phosphorus is actually taken up by the iron above the tuyeres. According to the reduction temperatures of manganese oxide, silica, and phosphoric acid by carbon so far published, the reduction of these substances below the melting point of pig iron has not been considered possible. Experiments carried out at the Eisenforschungsinstitut² have shown that in the presence of iron the reduction temperatures are

¹ *Metallurgie*, 1910, vol. vii. p. 403. Address to the Verein deutscher Eisenhüttenleute, Düsseldorf, May 30, 1926; *Stahl und Eisen*, 1926, vol. xlv. p. 1213.

² H. H. Meyer, *Mitteilungen aus dem Kaiser-Wilhelm-Institut für Eisenforschung*, 1927, vol. ix. p. 273.

lowered, so that a reduction of the impurities in the iron is already possible at the temperatures existing in the boshes. For example, the silicon derived from the reduction of silica is protected from re-oxidation by its ability to diffuse into the iron, and the lowering of the reduction temperature appears to be due to the presence of iron.

Mr. Kinney does not dispute the oxidation process before the tuyeres. On the other hand, in supposing that I envisage the oxidation of the iron only he is in error. The oxidation by the oxygen of the blast is certainly not selective, and the manganese, silicon, &c., are oxidised simultaneously with the iron. I expressed that opinion as early as 1910 in the following sentences: "That part of the fluid iron, which the oxidising atmosphere must pass, is from this cause more or less effectively refined, and not only the metallic iron itself but also carbon, silicon, and manganese are partly oxidised if they be present in the iron in appreciable quantity"; or, in another place: "Besides ferrous oxide, manganese oxide, silica, and phosphoric acid will be formed in greater or less quantities according to the composition of the pig iron produced."

In the present work, oxidation of iron only was discussed for the sake of brevity and in order to simplify the calculations. This is so far justified in that the oxidation of silicon, phosphorus, &c., follows the same course as ferrous oxide. Before the tuyeres of the blast-furnace, as in the Bessemer converter, an oxygen molecule in the blast is much more likely to collide with a molecule of iron than with a molecule of silicon or phosphorus. In the first instant, therefore, the chief product is ferrous oxide, which then in part reacts with the accompanying elements before it reaches the slag.

If, on the basis of the gas analysis, the proportion of oxygen to nitrogen be considered, it is found that close to the tuyeres the oxygen in the gaseous phase is diminished, and it can only be consumed in the oxidation of iron, manganese, silicon, &c. From such analyses it may be calculated that 15 per cent. of the oxygen in the blast is utilised in oxidation.¹

Mr. Kinney's objection that as a result of such powerful oxidation 54.5 per cent. of ferrous oxide must be found in the slag is fallacious. As indicated above, the reduction of ferrous oxide by carbon, manganese, silicon, phosphorus, &c., takes place in part before it reaches the slag layer. But, even though the whole of the oxygen were consumed in the oxidation of iron only and the ferrous oxide formed were reduced first from the slag, still would it be unnecessary for the slag to carry so much ferrous oxide as Mr. Kinney calculates. Many reactions are known to take place through an intermediate stage. The intermediate product is generally very difficult to identify, because its speed of decomposition is greater than its speed of formation. It is exactly the same with the oxidation of iron followed by the reduction of the

¹ *Stahl und Eisen*, 1926, vol. xlv. p. 1213.

ferrous oxide. The speed of reduction at the high temperature in the hearth is so great that the ferrous oxide is immediately reduced again by the coke as well as by the carbon, silicon, manganese, and phosphorus of the pig iron, and the presence of iron oxide in the slag in larger quantities is not found.

The formation of the steel-like iron masses, the so-called "bears," can only be imagined to occur through the interaction of an iron-oxide slag with pig iron lying below the level of the taphole.

Mr. Bohm also confirms by his experiments on Jernkontoret's blast-furnace that carbon, manganese, silicon, phosphorus, and sulphur are already absorbed by the sponge iron. The assertion that I am of the opinion that a reduction of these elements could not take place while the pig iron and slag are trickling through the coke mass above the tuyere plane, is nowhere expressed. On p. 72 it is stated only that the reactions could not be of great importance, as the time interval was too short.

With his ore, Mr. Bohm could observe only very slight carbon deposition. The cause of this was that, owing to the cooling of the furnace, air got access to the burden, probably causing the finely divided carbon separated from the carbon monoxide to burn, and also other changes in the burden occurred, so that his results are not very reliable evidence. I consider that under normal conditions a reduction of silicon, manganese, and phosphorus cannot take place in the hearth, and for this case also I cannot accept Mr. Bohm's analyses in support of his opinion. If the drops of pig iron are withdrawn with a test-ladle through a tuyere, oxidation in the air takes place and the analyses give results that are too low.

Both contributions confirm the accuracy of my hypothesis that the impurities in the pig iron are already taken up by the latter in the solid state. As early as 1910 I made the following remarks¹: "It is clear that not only the expenditure of fuel but also the output of the blast-furnace are immediately improved if it becomes unnecessary for the pig iron to carry into the hearth a supply of silicon and manganese to counteract the oxidising influence of the tuyeres. All precautions which restrict the space in front of the tuyeres in which an oxidising atmosphere is present must produce good results not only in regard to fuel consumption but also output. The preheating of the blast was the first step in this direction."

¹ *Metallurgie*, 1910, vol. vii. p. 409.

THE EFFECT OF VARYING ASH IN THE COKE ON BLAST-FURNACE WORKING.¹

BY C. S. GILL (CONSETT).

INTRODUCTION.

CONSIDERABLE attention has been given recently to the coke for blast-furnace use, and valuable investigations have been and are taking place in this country and in America, in order to define those attributes of blast-furnace coke which give the most satisfactory results in practice. The author feels, however, that so far this question, which is, perhaps, the vital governing factor in successful blast-furnace operation, has been very largely left to scientific observers, and it is difficult to obtain actual figures of the results produced in large-scale practical operation. As he has fortunately been in a position to make some practical tests, this paper is written to make known the information thus gained, and if possible to encourage others also to publish figures showing the effect of variation in the quality of coke supplied to the furnaces.

It has frequently been stated that the blast-furnace manager does not really know what sort of coke he requires, and, if this means an exact definition of the coke for all blast-furnaces under all conditions, this may be true. There would appear to be little question that the coke which gives satisfactory results under certain conditions of furnace lines and ore to be smelted might, under other conditions, give less satisfactory results, and probably this accounts for the fact that there is frequently a discrepancy between the ideal cokes as specified by different furnace managers. There is no doubt, however, that they all agree that the coke they require is one which, with their individual conditions of ore, &c., shall give quick driving of the furnace together with low coke consumption.

¹ Received June 1, 1927.

Whilst the above is true, there are some characteristics of coke upon which all blast-furnace managers are unanimous ; as has been frequently pointed out, a good blast-furnace coke should be low in sulphur, ash, and moisture, of regular analysis, free from fines or breeze, and of such physical strength as to resist the abrasive action of the furnace itself. There is another characteristic which is more difficult to define, sometimes spoken of as " reactivity " or " combustibility," and which for practical purposes means " that characteristic of coke which promotes quick, regular, and economical driving."

As to which attribute of coke is the most important, it is not always easy to say. High ash or sulphur are either of them definite evils, but if they are regularly and consistently high, it is possible to so burden the furnace that the evil results are confined to increased expense in the production of the pig iron. On the other hand, a fluctuating ash is an unmitigated evil, as it is impossible to so arrange the burden that the furnace shall give reasonably consistent results if the ash in the coke is varying from hour to hour even to the extent of $1\frac{1}{2}$ or 2 per cent.; and probably many practical operators would agree that they prefer a coke consistently carrying 12 per cent. of ash rather than one in which the ash fluctuates from 9 per cent. to 14 per cent.

In presenting figures obtained in practice, one is always faced with the difficulty of making the results truly comparable, owing to the multitude of varying factors which enter into any large-scale operation ; if these variables are ignored, entirely erroneous conclusions may be drawn. The following results are, however, comparative in the sense that the ore mixtures, type of iron produced, stove temperatures, &c., were maintained as nearly constant as possible.

EFFECT OF FLUCTUATING ASH.

It has been stated above that a fluctuating ash is an unmitigated evil, and as an illustration of this the following is cited :

Early in 1924 very serious trouble was experienced owing to the fluctuations in the quality of the iron from cast to cast. Repeatedly the quality would change from No. 1 grade to practically white iron within a few hours, and then back again to good iron.

The average ash content of the coke did not fluctuate to an abnormal degree from day to day, but after the strictest supervision of the weighing of materials and the charging of the furnaces had revealed nothing wrong, the conclusion became inevitable that the root of the trouble must lie in the coke.

Arrangements were made for hourly samples of the coke to be taken as it was being charged to the furnace over a period of

TABLE I.

Time Sample Taken. Hour.	Ash as Received. %	Average. %	Sulphur in Pig Iron.	
			Top of Cast. %	Bottom of Cast. %
11 P.M.	14.56	14.53	0.194	0.252
12 midnight	14.13			
1 A.M.	12.03			
2 A.M.	14.82			
3 A.M.	15.84			
4 A.M.	15.81	13.06	0.040	0.091
5 A.M.	15.26			
6 A.M.	12.56			
7 A.M.	13.29			
8 A.M.	13.65			
9 A.M.	10.55	10.74	0.030	0.025
10 A.M.	9.57			
11 A.M.	10.18			
12 noon	12.34			
1 P.M.	11.40			
2 P.M.	10.35	13.28	0.102	0.117
3 P.M.	10.59			
4 P.M.	10.81			
5 P.M.	14.63			
6 P.M.	14.02			
7 P.M.	13.51	14.33	0.065	0.222
8 P.M.	13.43			
9 P.M.	13.08			
10 P.M.	15.58			

twenty-four hours. These samples, weighing from 7 to 8 cwt. each, were taken from all the slides from which the coke was being filled, and so were representative of what the furnace was receiving.

From the dimensions of the furnace and speed of driving it was not difficult to calculate with tolerable accuracy how long it took the coke to reach the hearth of the furnace and, from this, to identify the cast or iron corresponding to the coke charged at any given time. The results are shown in Table I., in which the

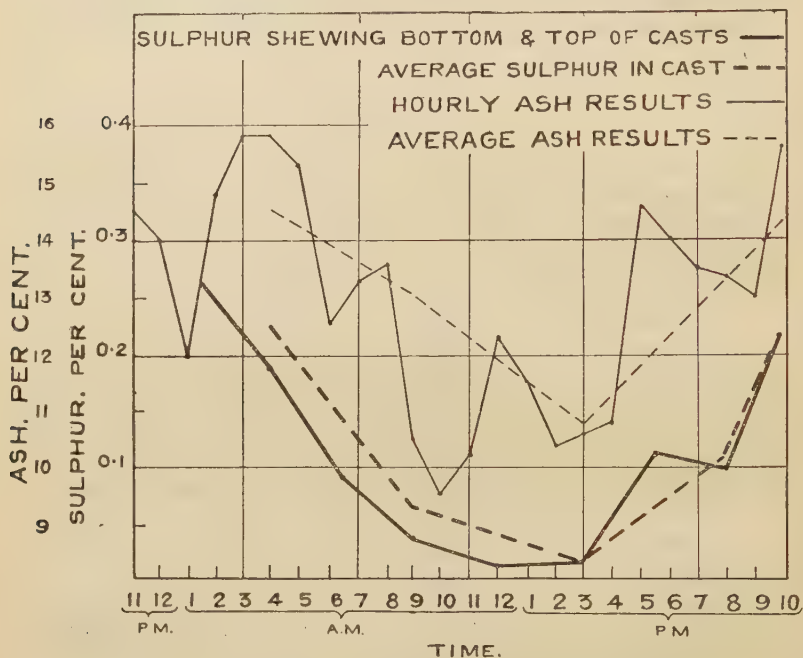


FIG. 1.

samples of coke have been apportioned to suit the length of time which elapsed between the different casts—roughly, $5\frac{1}{2}$ hours.

The table is self-explanatory, but in view of the great difference in the quality of the iron corresponding to what might be considered a comparatively small variation in the percentage of ash, it should be remembered that each increase in ash not only reduces the percentage of total carbon in the coke, but increases the weight of slag formed, which in its turn requires an increased amount of carbon to raise it to its melting point and superheat it to the temperature of the furnace, so reducing considerably the

carbon available for the other necessary chemical and thermal reactions of the furnace operation.

Fig. 1 shows the hourly ash figures, and the corresponding sequence of sulphur results in the iron produced is appended, and serves to illustrate how sensitive the furnace is to quite small variations in available carbon.

As the casts were run on the pig-beds commencing at the bottom and finishing at the top, the sulphur results in the graph are shown in the order in which the iron was made in the furnace.

EFFECT OF CONSISTENT ASH.

The following illustration is given as showing the effect of changing the ash in the coke supplied to the whole of the blast-furnace plant. It has, perhaps, special interest for the following reasons :

- (a) The results are averaged over five weeks in each case. Period I. gives the figures for five weeks immediately prior to the change, and Period II., the corresponding figures for the five weeks immediately following the change, omitting altogether the week during which the change-over was effected.
- (b) The figures are actual averages of the results at a number of furnaces, and not of one selected furnace.
- (c) Both cokes were similar in physical characteristics, being made in the same ovens, and under identical conditions.

	Period I.	Period II.
Average ash in the coke	12.15 %	9.76 %
Average weekly make of pig iron . .	3311 tons	3819 tons
Tonnage of No. 3 grade	210 "	134 "
Percentage of No. 3 grade	6.34%	3.51%
Average pressure of blast	5½ lb. per sq. in.	4½ lb. per sq. in.
Percentage increase in make . . . .	...	15.4%
Reduction in coke consumption . . . .	...	1.01 cwt. per ton of pig

The above figures speak for themselves, but they do not give a full idea of the improvement which took place in the practical operation at the furnaces. During both periods the endeavour was made to produce iron high in silicon for sale purposes, but during Period I. the furnaces were "stiff" and the results

unsatisfactory, whilst during Period II. the furnaces worked freely and gave consistently good results.

On another occasion a similar change-over was made on one furnace only from a coke containing 12·5 per cent. of ash to one averaging 8·75 per cent. of ash, and the test was kept up for nearly five weeks, during which complete records of all analyses, temperatures, pressures, &c., were carefully gathered, but for the purpose of this paper it is only necessary to give the following comparison :

	Before Change-over.	After Change-over.
Percentage ash in coke	12·5%	8·75%
Average weekly make of pig iron	950 tons	1190 tons
Percentage increase of make . . . . .	...	25·25%
Reduction in coke consumption . . . . .	...	1·76 cwt. per ton of pig*

All the above results were obtained in small furnaces, the most recent of which was built in 1880. Fig. 2 is a dimensioned sketch, which is representative of all, though there are minor differences.

An examination of the economies effected in the two tests given proves interesting. Thus in the case where all the furnaces were changed over from coke with 12·15 per cent. of ash to coke with 9·76 per cent. of ash, an improvement in coke consumption of 1·01 cwt. per ton of pig was the result.

$$\frac{\text{Saving in coke, 1·01 cwt.}}{\text{Reduction in ash, 2·39\%}} = 0·42 \text{ cwt. of coke saved per 1\% reduction in ash.}$$

At the same time an increased make of 15·4 per cent. resulted.

$$\frac{\text{Increase in make, 15·4\%}}{\text{Reduction in ash, 2·39\%}} = 6·4\% \text{ increase in make per 1\% reduction in ash.}$$

Working out the results obtained in the second case, where one furnace was changed from coke with 12·5 per cent. of ash to coke with 8·75 per cent. of ash, the figures obtained are :

$$\left. \begin{array}{l} 0·47 \text{ cwt. of coke saved and} \\ 6·7\% \text{ increase in make} \end{array} \right\} \text{ per 1\% reduction in ash.}$$

These figures are remarkably consistent, in view of the fact that the two tests were carried out at quite different times and had no immediate relation to each other ; they provide a basis upon which the whole question of the provision of low-ash coke for blast-furnace use may be worked out from a financial standpoint.

Thus, in a case where two cokes were available, containing 12 per cent. and 9 per cent. of ash respectively, the reduction in

coke consumption by the use of the latter would be $0.42 \times 3 = 1.26$ cwt. per ton of pig. This, based on coke at 20s. per ton at the furnaces, is equivalent to a direct saving of 1s. 3d. per ton of pig made, and it is a simple matter, knowing the coke necessary to make 1 ton of pig iron, to work out what extra price could be

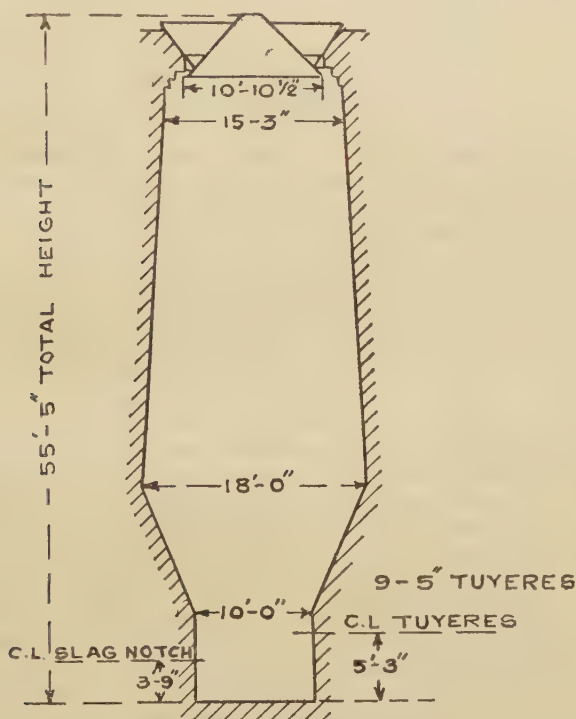


FIG. 2.

paid for the lower-ash coke as compared with the other, whilst still maintaining a margin in costs.

The indirect saving due to increased output, more regular product, &c., can only be estimated with a knowledge of local conditions at each plant, but the gain is material.

In conclusion, the author wishes to express his thanks to E. J. George, Esq., for permission to publish the figures given in this paper.

DISCUSSION.

Professor HENRY LOUIS (Vice-President), in opening the discussion, said Mr. Gill's paper was of very great interest at the present time, when it was necessary for everybody to strive to introduce every possible economy and to keep down costs. The author stated that there was a direct saving of 1s. 3d. per ton by the use of coke containing 3 per cent. less ash. Less ash in the coke under modern coal-mining conditions could be obtained in one way only, namely, by cleaning the coal. Apparently, therefore, the saving to which the author referred must be obtained by coal cleaning methods. Technically, coal cleaning had, within the last decade at any rate, improved so greatly in this country that it was in a fairly strong position. There were many coal cleaning plants in use in which it was possible to clean the coal down to within 1 per cent. of the theoretical—that is, of the results shown by a coal washability curve—so that the technical question might be said to be pretty thoroughly solved. The outstanding problems were of an economic character. He had the pleasure to be present at the coal cleaning conference held some two months ago, over which Dr. Lander had presided, at which it was freely stated by several of the leading people engaged in coal cleaning that if the coal user would pay them sufficient to make it worth their while to clean the coal, they could and would do so. It seemed to him that the paper helped to show how much users could afford to pay for that process. The author showed in his paper that with three units of ash less in coke there was a direct saving of 1s. 3d. per ton. In addition, there were a number of indirect savings which it was perhaps difficult to calculate, but a good many of which could be seen; for instance, three units of ash less in the coke meant, roughly speaking, about two units of silica less in the coke, and that would mean something of the order of five units of limestone less in the blast-furnace charge, and, taking an average slag composition, something of the order of probably six units of slag less to handle. In addition there was the increased output from the same blast-furnace, which meant saving in labour and saving in book charges, such as interest, depreciation, and amortisation of the blast-furnace plant, together with a whole number of other smaller items, which all together he roughly estimated at something like 1s. for the three units. He hoped the author would state how far he agreed with that rough guess. He therefore estimated that, approximately, the three units of ash less in the coke should give a total saving of something like 27 pence. That was one side of the question, the other side being the cost of the coal cleaning. Coke with a diminution of 3 per cent. of ash corresponded in round numbers to a diminution of about $2\frac{1}{4}$ per cent. of ash in the coal. He had never

known of coal being cleaned to remove only $2\frac{1}{4}$ per cent. of ash, but had known several cases where twice that amount was taken out. The cost of coal cleaning with modern plants, allowing for power, labour, interest, amortisation of plant, and so on, usually came to between 3d. and 6d. per ton. In addition, it was necessary to bear in mind that the amount of vendible coal produced was diminished. To get $4\frac{1}{2}$ per cent. of ash out diminished the vendible coal by usually about 10 per cent. Taking coal at 12s. 6d. a ton (which about corresponded with coke at 20s. a ton), that gave 15d. to add to the 6d. he had previously mentioned, or 21d. to produce a decrease of 6 per cent. of ash in the coke. If by spending 21d. on cleaning coal it was possible to save twice 27d., *i.e.* 54d. (reckoning a ton of coke to a ton of pig iron), there was evidently a very considerable margin to play with. It looked to him as if the author's figures showed the possibility of amply remunerating the coal producer for cleaning his coal, and at the same time giving the blast-furnace man something quite handsome in hand to make it worth his while to pay for clean coke. He looked upon the paper as an extremely important one, because it showed the possibility of paying well for cleaned coal (and therefore clean coke) for the use of the blast-furnace man, and from that point of view he had been exceedingly interested in the paper.

Mr. J. HENDERSON (Member of Council) said he thought the paper illustrated a point he had made in discussing a previous paper, namely, the importance of regularity. A calculation had recently been made at the Frodingham Co.'s Works that the saving effected by a reduced content of ash would be not less than 6d. for each 1 per cent., possibly more. That was the direct savings, and did not cover the indirect or consequential savings referred to by Professor Louis. The enterprise of the Consett Co. in carrying out such a large-scale experiment was certainly very admirable, and he thought it was very good of the company to allow the results to be published. It was extremely difficult, as he had said before, to say just exactly what the result of any change in a blast-furnace would be, but there could be no doubt that lower ash content in the coke was a matter of very first-class importance.

Mr. E. ADAMSON (Sheffield) said that the calculation based on the table given on p. 95 gave the ratio of reduction of coke consumption to ash reduction as 1 : 2.3 (1.01 : 2.39), while that based on the table on p. 96 gave the ratio as 1 : 2.1 (1.76 : 3.75). He thought it would be of interest if Mr. Gill would explain the reasons for the difference in the ratio between the coke consumption saved and the ash content reduction, and also give the actual coke consumption in each case.

Mr. EDWIN H. LEWIS (Wishaw) said that three years ago, in an address which he gave to the West of Scotland Institute, he took the question of ash in coal as part of his subject. In Glasgow they always

took coal for comparison and not coke. At that time he calculated theoretically that, after taking into account the loss of carbon owing to the presence of ash, the loss of volatiles, the increased use of limestone necessary to flux the additional ash, and also the loss of carbon due to solution by the CO_2 from that limestone, with the price of coal in October, 1924, the coal was worth to him 9.4d. per ton less for each 1 per cent. of ash in the coal. Coming to the question of pig iron, of course the more ash there was the greater was the increase in cost at each step. At that time 2 per cent. increase in ash in the coal, which would roughly correspond to 3 per cent. increase in the coke, with the same coal that he mentioned previously, would have cost 2s. 10½d. per ton extra for the manufacture of their pig iron. Those were very startling results, because no account had been taken of the very serious effect upon output, with resultant increase of standing charges and of wages cost per ton. He thought the corresponding figure to-day for that 2s. 10½d. would be about 2s. 2d.

The PRESIDENT read the following communication received from Dr. R. LESSING (London):

Mr. Gill is to be congratulated on bringing forward actual working results showing the effect of coke ash on the blast-furnace process. From investigations extending over many years into the ash-forming constituents of coal and their influence on the coking process, and subsequently on the utilisation of coke, I have come to conclusions for which Mr. Gill now furnishes corroborative evidence from large-scale working. In calculating the economic advantages of low ash in coke, Mr. Gill singled out the item of reduction in coke consumption, which he very fairly estimates at 1s. 3d. per ton of pig for a 3 per cent. reduction in coke ash. I have pointed out on several occasions that I consider very much lower ash percentages within the range of practical politics, and I venture to suggest that the increments of savings will grow the further the ash percentage is reduced, so that for a drop from 9 per cent. to 6 per cent. the saving in coke consumption may be considerably more than 1s. 3d. as for the first 3 per cent. Moreover, the sum total of the indirect saving due to increased product, more regular product, &c., which the author considers to be "material," will be of an order of magnitude even larger than that from the lower coke consumption. The saving in capital charges alone, which will of course differ widely from case to case, may amount, on the basis of a 25 per cent. increase of output for a 3 per cent. ash reduction, to rather more than 1s. per ton of pig made, to which a few pence will have to be added in respect of the re-lining fund. The monetary value of an enhanced quality or regularity of the product is difficult to assess, but once the dependence of these factors upon the quality of the coke has been recognised, the tendency will be to insist on a fuel which will guarantee such quality, regardless of any saving that might be incidentally effected. In amplifying a conclusion put forward in

my Cantor Lectures on "Coal Ash and Clean Coal,"¹ I suggest that the iron and steel industry will, in the near future, feel constrained to insist for their solid fuel on a coke containing only a fraction of the proportion of mineral matter which is customary to-day.

The PRESIDENT, continuing, expressed entire agreement with Dr. Lessing as to the importance of the influence of low ash, both directly and indirectly. The less ash or mineral matter the better, while the question of the regularity of the coke was of equal if not greater importance.

Mr. GILL, in reply, thanked the various speakers for their kind remarks and for their very interesting comments put forward in the discussion.

¹ *Journal of the Royal Society of Arts*, 1926, vol. lxxiv., Jan. 15, pp. 182-197; Jan. 22, pp. 205-218; Jan. 29, pp. 224-241.

HIGH-FREQUENCY INDUCTION MELTING.¹

By D. F. CAMPBELL, M.A., Assoc.R.S.M., F.G.S. (LONDON).

INDUCTION heating was first applied to the steel industry about twenty-five years ago, and the theoretical work of Ferranti, Colby, and others resulted in industrial furnaces being developed by Kjellin, Frick, and Rodenhauser.

Although a few of these furnaces are still used, many have been abandoned on account of certain inherent difficulties in their metallurgical and electrical characteristics. In most cases, special low-frequency generators are used to obtain a reasonable power factor, and these are both expensive and large, while the generator capacity cannot be used for general works' purposes in cases of emergency, owing to the exceptional periodicity. Metallurgically, the ordinary induction furnace has serious limitations; the molten metal is contained in a hearth of complicated form with a large area of refractory material exposed to the steel, which involves high maintenance cost and lack of homogeneity in the steel, while the slag is only melted with difficulty, so that efficient refining is impossible. It is also necessary to leave, or place, a quantity of steel in the furnace after each heat to form the secondary connection, which is a serious difficulty when making alloy steels, as the weight of steel cannot be determined with sufficient accuracy to work to close specifications, and the change from one quality of steel to another is difficult. In the case of high-frequency induction furnaces the crucible can be completely emptied after each heat.

A characteristic form of the ordinary low or standard frequency furnace is shown in Fig. 1, which illustrates the complicated form of bath, while Fig. 2 indicates the bath of a high-frequency furnace. In the former case it is necessary that the bath of molten metal should be annular in form, so that it may surround and form the secondary of one or more iron transformer cores, but in

¹ Received July 5, 1927.

the case of high-frequency furnaces, ironless induction is used and heat is generated by eddy currents, so that a cylindrical or spherical bath can be used—the ideal form of metal container for metal melting—and no iron core is required.

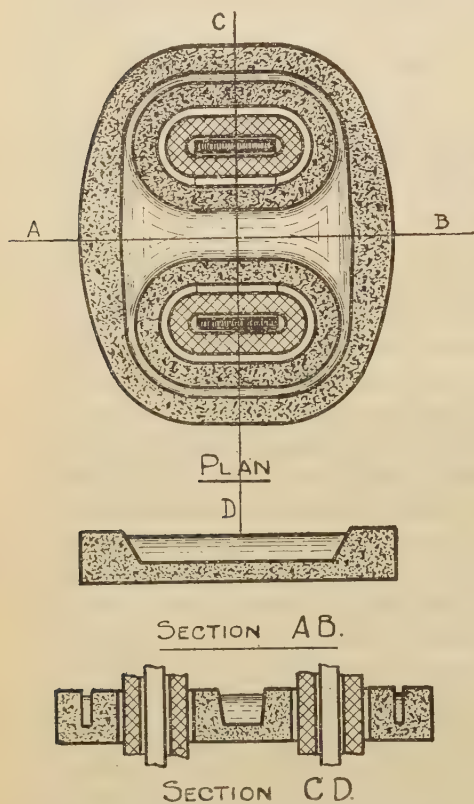


FIG. 1.—Rodenhauser Low-Frequency Furnace.

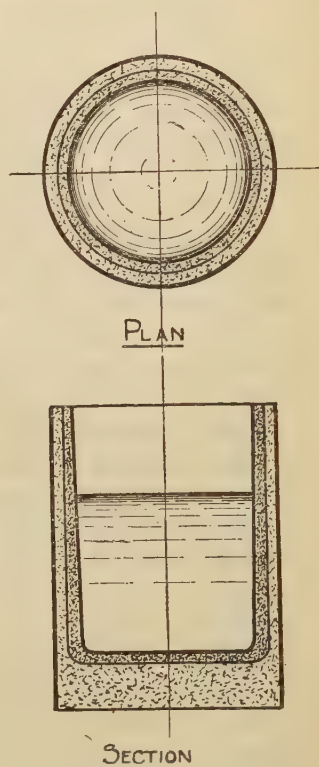


FIG. 2.—Northrup High-Frequency Furnace.

The use of high-frequency electricity for melting metals in the laboratory has been generally recognised as one of the most important advances of recent years, owing to the new physical conditions under which metals can be melted or heated. This method is now available for the industrial production of steel, and is applicable to the melting of tool steel and the manufacture of

small steel castings, especially those that are required to replace small malleable iron parts which lack the reliability that is demanded by modern engineering practice.

Low or normal frequency induction furnaces are electric transformers, in which a ring of metal to be melted surrounds a laminated iron core, round which primary coils are wound. With high-frequency currents the iron core is not necessary, and the furnace bath may be constructed in a cylindrical form, similar to that of an ordinary crucible, which is ideal for low heat losses and good metallurgical conditions for the maintenance of refractory linings. A low power factor is characteristic of this design, but this is easily corrected to any desired extent by the use, in the case of the Ajax-Northrup furnace, of condensers at a reasonable cost and efficiency.

Ironless induction at normal frequency for small-sized furnaces, such as those required for tool steel manufacture, involves an expenditure on electrical machinery for power factor improvement which is prohibitive, both as regards first cost and power consumption, as compared with the Northrup system of high-frequency generators, driven by motors, with condensers.

Obtaining machinery for the production of high-frequency currents at reasonable cost in sufficiently large units was the problem which had to be solved before the industrial use of the furnace could be assured, as the laboratory units were supplied by current produced from delicate and complicated generators involving the use of spark gaps, with condensers and transformers of special design. The capacity of each individual generator was limited to about 40 kva., and this equipment was not sufficiently large or robust for the arduous conditions in steelworks.

This difficulty has now been entirely overcome, and high-frequency rotary generators, similar in general appearance to an ordinary high-speed motor-generator, can now be obtained at reasonable cost from a number of British and foreign manufacturers. With this equipment the furnace installation is simple, as it only consists of the motor-generator, a bank of condensers to improve the power factor of the furnace circuit to any required degree, and a tilting furnace of simple but unusual design. In addition, suitable control instruments, regulator and switches complete the electrical plant.

The furnace itself is of remarkably simple construction, and consists of a crucible or metal container, surrounded by about an inch of heat-insulating sand ; around this a helical coil is wound, which is usually maintained at a low temperature by circulating water. This coil is the inductor carrying the water and high-frequency current, and the heat is generated within the metal itself inside the crucible, so that the walls merely serve the purpose of a container, and no heat is passed from the outside of the crucible to the metal within. This has an important bearing on the crucible consumption, which is only a fraction of that in an ordinary furnace where heat is driven through the crucible, and wear and tear occurs on the outside and the external temperature is necessarily higher than that of the metal. No mechanical strength is required, as the crucible is always well supported by the packing of sand, and it is not withdrawn for casting.

The inductor coil is built into the furnace body, which is made of wood or other material in which heat will not be produced by induction. The body, which is easily replaceable, is generally fixed in a cradle arranged for nose-tilting by electric motor, so that there is little or no movement of the crucible spout during teeming operations.

The metallurgical characteristics of the furnace are interesting, and some operations that were impossible in the past, such as the remelting of stainless iron without absorption of carbon or sulphur, can now be accomplished.

Heating and melting are effected very rapidly, as induction heating makes it possible to generate heat throughout the charge of metal simultaneously, instead of heating from the surface only, as is the case with all fuel furnaces. For melting operations and the heating of bars this is sometimes advantageous, as the risk of oxidation and contamination from furnace gases is reduced, and for making small castings the frequent melting of small quantities facilitates economy in general foundry practice. As an example of speed, it is possible to melt 18 per cent. tungsten steel in 3-cwt. lots in forty-five minutes, which is less than one-quarter of the time normally required to melt one-third of this charge in a crucible in a coke fire.

The following record shows a typical day's work with a small

unit of only 100 kva., pouring 3 cwt. of high-grade nickel-iron alloys from a siliceous crucible entirely free from carbon. The carbon in the alloy was in every case below 0.04 per cent.

<i>Heat No.</i>	<i>Date.</i>	<i>Time.</i>	<i>Total Time.</i>	<i>Charge.</i> Lb.
62	1/2/27	9.20-10.50 A.M.	1 hr. 30 min.	336
63	"	10.55-12.00 "	1 " 05 "	336
64	"	12.02- 1.12 P.M.	1 " 10 "	336
65	"	1.15- 2.25 "	1 " 10 "	336
66	"	2.30- 3.50 "	1 " 20 "	336
67	"	4.00- 5.15 "	1 " 15 "	336
68	"	5.20- 6.30 "	1 " 10 "	336
69	"	6.35- 7.50 "	1 " 15 "	336
70	"	7.55- 9.00 "	1 " 05 "	336
Total: 9 heats				3024

Total melting time 11 hrs. 0 min.

Total time, melting and pouring . 11 " 40 "

The cost of high-frequency furnace melting is about equal to that of small Héroult arc furnaces, as the power consumption, including all losses, is about the same, and the extra cost of crucibles is approximately equal to that of electrodes. The steel, however, is made under crucible conditions, with the advantage of absolute homogeneity and an intensity of mixing, and a melting temperature which is only limited by the refractories and the melter operating the furnace.

The refining and purification of steel in high-frequency furnaces is a question that is receiving much attention. In many cases, tool steel-makers have no desire to refine, but there are cases of interest, notably in connection with heat-resisting steels and alloys, in which absence of carbon is desired. It has been sometimes supposed that refining would not be possible in this type of furnace owing to the comparative failure of the old induction furnaces of normal and low frequency, which have a bath of complicated form with narrow channels, an excessive slag line on the refractories, and which work with low-temperature slags. The arc furnace is an efficient refiner owing to its high slag temperature, but it is only when successive particles of steel are brought in contact with hot slag that refining occurs, and the speed of refining necessarily depends upon the rate at which

the impure steel is submitted to the refining action of the lower slag surface.

In high-frequency furnaces the electric current causes a very rapid rotating movement of the metal in the vertical plane, the speed of rotation being so great that in a bath of steel 15 in. in diameter the centre of the bath rises more than 1 in. above the metal at the circumference. This rapid circulation of the metal in contact with the slag quickly refines the metal, the heat transference between the metal and slag being sufficient to maintain the latter in a fluid condition, and to ensure that intimate contact which is so essential to rapid and efficient refining. For example, a bath of steel containing 0·7 per cent. of carbon was left in contact with a slag containing oxide of iron for ten minutes and the carbon was then reduced to 0·24 per cent.

The remelting of low-carbon chromium steels without any increase of the carbon contents is an industrial application of the utmost importance for the recovery of scrap stainless iron and heat-resisting alloys. The remelting of these alloys without absorption of carbon or impurities from furnace gases has now become a commercial possibility; it should cheapen production and improve the quality of these alloys, which are of such great importance to present-day metallurgical and engineering developments.

The following analysis of a stainless iron ingot made from carbon-free ferro-chromium and a Swedish iron of exceptional purity indicates that very low-carbon alloys can be made without difficulty :

Chromium	.	.	.	.	13·5
Carbon	.	.	.	.	0·03

Two applications of high-frequency melting may be described as typical of the most obvious uses for this type of furnace, a photograph of which is shown in Fig. 5 (Plate III.).

Installations for the manufacture of tool steel usually consist of furnaces, each of 400 to 500 lb. melting capacity and each supplied with 150 kva. from a motor-generator, the power factors of the furnaces being corrected by condensers. The output of such a furnace is about 450 lb. per hour, or about 4 tons per 24 hours, the exact output depending upon the quality of steel made and the

number of ingots cast. The furnaces are placed below the working platform so that the top of the furnace is at floor level, which is convenient for charging and for slag removal before casting. The ingots are arranged so that the steel is cast direct from the nose-tilting furnace, a tun-dish being used to avoid cutting the moulds. The moulds are placed so that their tops are at the same level. When a number of small ingots have to be poured, the moulds are brought before the spout of the furnace at the correct level and distance by a turntable on ball-bearings.

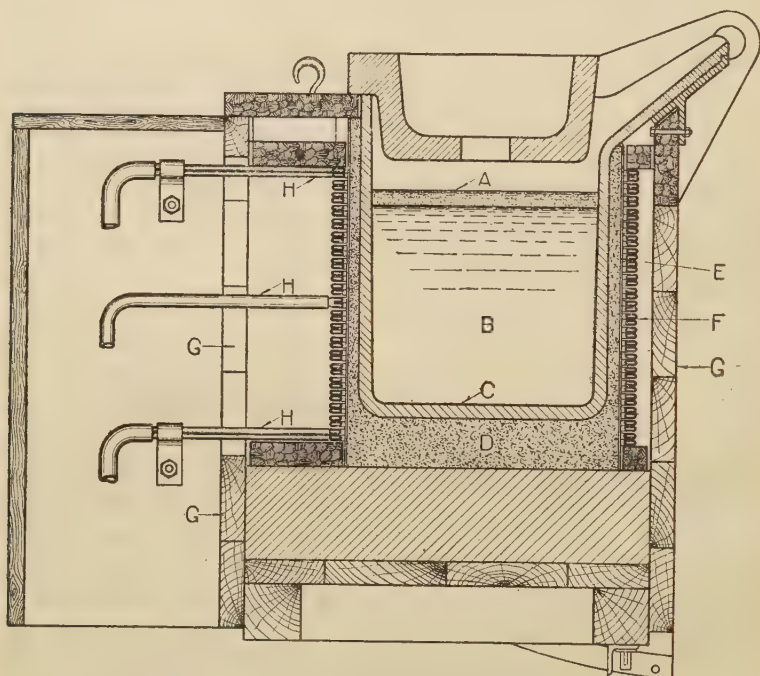
A spare body, consisting of a wooden box with spare coil, crucible, and refractory sand, is provided, and can be put in position in a few minutes when it is necessary to change crucibles.

The diagrams, Figs. 3 and 4, show a typical installation in a Sheffield steelworks.

Another typical application is the use of these furnaces in foundries making small castings. For example, a foundry making motor-car castings, where the average weight is between 2 and 3 lb., can reorganise the system of moulding and general organisation, if small quantities of hot steel are frequently available, and ladles and handshanks can be eliminated. Each motor-generator is arranged to heat two or more furnaces, which are worked alternately, the current being switched from one to the other directly the first is ready for pouring. There is no loss of heat by transfer to ladle or handshank, and the furnace, being well heat-insulated, keeps the steel hot during the casting period. The furnaces, which are light and small, and arranged for nose-tilting, may be on bogies, or the moulds may be conveyed to the furnace spout at the correct height by belts or turntables provided with suitable packing pieces to bring them to the correct height. For small repetition work this method offers obvious advantages.

The high and uniform rate of heating of a mass of steel by high-frequency induction is also being applied to the heating of billets for tube-making, with prospects of success, and by special study it has been found possible to develop useful apparatus for the heating of mining drill steel, and the continuous heating of $\frac{1}{4}$ -in. steel rods at the rate of 60 ft. per minute. The latter apparatus is likely to prove of value for patenting wire and rods, for the heating of bars for nut and bolt making, and for miscellaneous forging operations.

High-frequency generators of 600 kva. are in regular commercial operation, but the ultimate size of high-frequency heating units cannot yet be defined. Generally speaking, there appears to be no technical difficulty in the construction of large generators

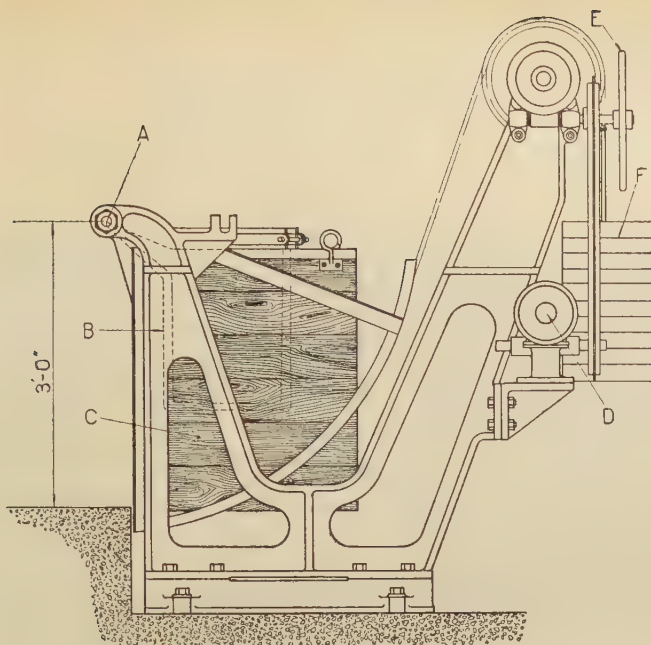


- | | |
|------------------------|-----------------------------------|
| A. Molten slag. | E. Insulating sleeve. |
| B. Molten metal. | F. Inductor coil. |
| C. Crucible. | G. Furnace body. |
| D. Insulating packing. | H. Electrical and water conduits. |

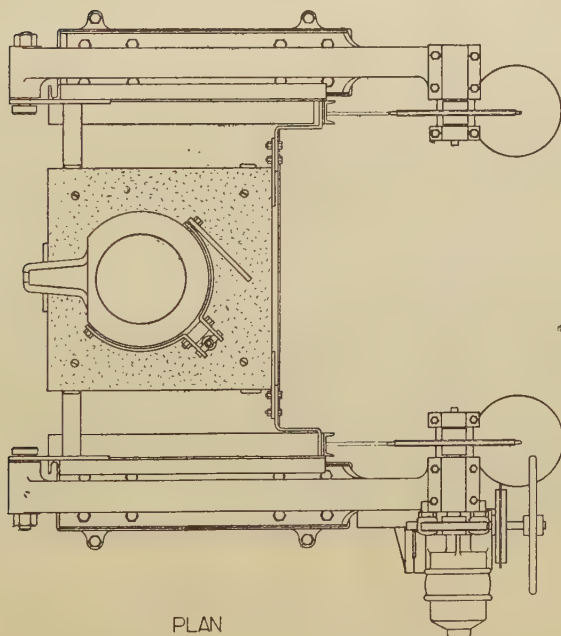
FIG. 3 —Cross-Section of Ajax-Northrup High-Frequency Furnace.

and the building of furnaces of considerable tonnage, if commercial considerations permit the application of this form of heating.

The scope of high-frequency heating is expanding as rapidly as electrical machinery constructors can meet the requirements imposed upon them, and progress both in melting and heating of steel is being rapidly accomplished. Its value is, however, already well established as a method of making crucible steel of remarkable homogeneity at a low cost, with the elimination of the hard physical labour inseparable from present methods.



SIDE ELEVATION



PLAN

- A. Spout of furnace on the axis of tilting trunnion.
- B. Crucible.
- C. Furnace body.

- D. Tilting motor.
- E. Hand-wheel for tilting.
- F. Counter-weights.

FIG. 4.—Plan and Side Elevation of Ajax-Northrup High-Frequency Furnace.

DISCUSSION.

The PRESIDENT, in inviting discussion, said he had had the pleasure of seeing one of the author's furnaces operating about a fortnight ago, and it was a most interesting sight to see the molten steel pouring out of a furnace encased in a wooden box. The temperature outside the furnace was so low that there was not the slightest risk of the wood becoming ignited, but nevertheless molten steel was pouring out from the interior. It was essentially a crucible furnace, in which the heat was developed in the centre of the mass, and during the melting very little alteration took place in the composition of the charge, so that within very narrow limits the finished steel would be of the same composition as the original metal charged. During his visit the bottom came out of the crucible in the manner described by the author, but within half an hour another crucible was fitted, and the furnace in operation. As it flowed from the crucible the metal chilled on the coil, but it did not destroy it, and was easily removed. He would like to know how long a charge of, say, 3 cwt. could be "held" in the furnace; he presumed that it would not be for long, as cooling would take place relatively rapidly.

Professor C. H. DESCH, F.R.S. (Member of Council), said that he was a strong believer in the principle of high-frequency heating. Although he had not had any experience of the particular furnace referred to in the paper, he had seen the high-frequency induction furnace working very successfully in America with nickel alloys, and he had had experience with the earlier type of high-frequency induction furnace, namely, the Ajax-Northrup furnace. That was used in Sheffield University for experimental melts, and it had proved to be extraordinarily useful. It was possible to melt material of very high melting point in a very short time without any danger of contamination. They made their own crucibles in the University, and it was unnecessary to make them of great strength, because they were always packed in zirconia sand, so that a cracked crucible did not cause a mishap. It was very instructive to watch the melting going on. The process was a very rapid one, taking only a little more than half an hour to melt one of the charges, and the loss of heat was small. A short time ago they were melting about 10 lb. of pure Swedish bar, and at the time the metal was in a molten condition they were still taking the lid off the crucible with their fingers; it was then just getting uncomfortably hot. That particular furnace worked with a frequency of about 18,000. The great recent improvement was that the frequency had now been brought down to about 500, so that instead of having to use the very difficult and troublesome spark gap as a source of high-frequency current a

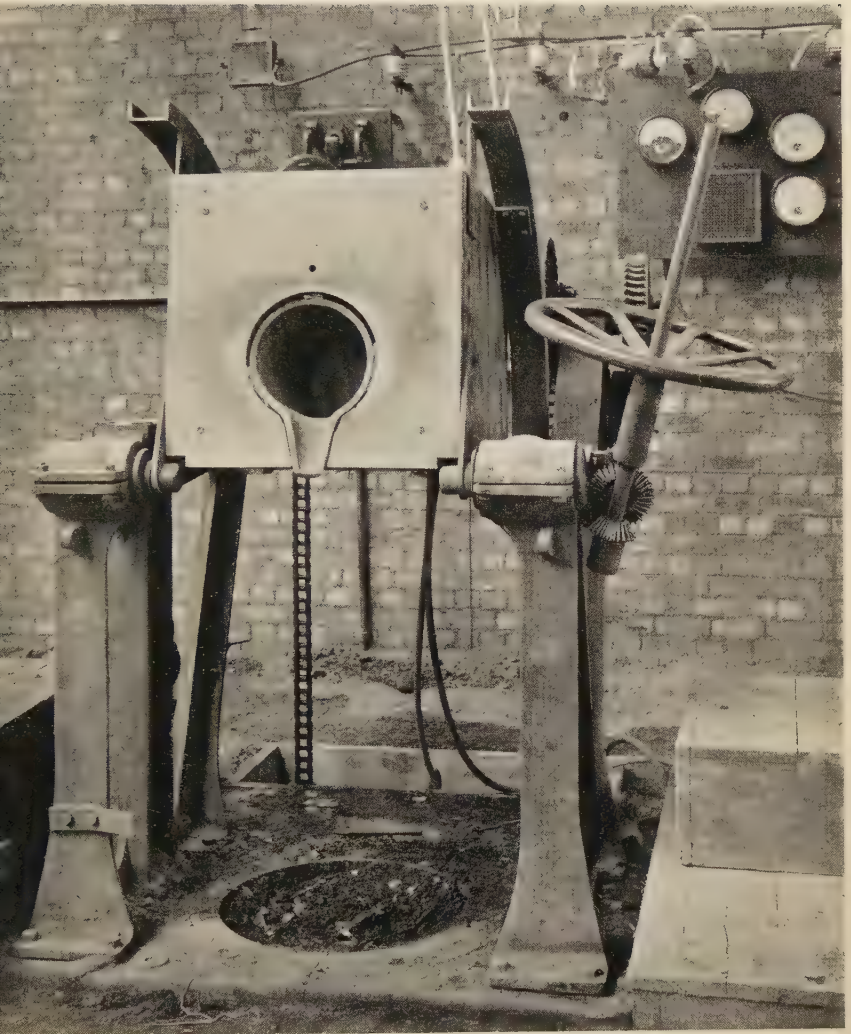


Fig. 5.—An Ajax-Northrup High-Frequency Furnace capable of melting 3 cwt. of high-speed steel per hour, in the tilted position.



rotary generator was used. It was very remarkable that with such comparatively low frequencies efficient heating could still be obtained.

From the metallurgical point of view, he desired to add a word of warning in connection with the melting of high-class steel. In Sheffield crucible practice the really essential feature was the killing fire at the end of the operation. For some time the steel was lying in the crucible in a perfectly tranquil state, and the tiny particles of slag floated up to the top and were removed as a button at the time of casting. In high-frequency melting the metal was in a very turbulent condition; the convection currents in the steel were so violent that there was a difference in level at the top. That tended to prevent the elimination of very small slag particles, and if one switched off the current and left the metal in a tranquil state, the heat capacity was so small and the temperature of the surrounding space was so little above the atmospheric temperature that as soon as the current was shut off the metal began to cool down very rapidly. He therefore desired to utter that word of warning. There was the great advantage, however, in high-frequency melting that as there was no contamination from furnace gases and no carbonaceous material in the crucibles it was possible to start with quite pure materials and enclose the whole apparatus in a vacuum, practically no slag being formed. It was possible, therefore, to manufacture steel without having any slag introduced, and in that case the turbulence of the molten metal would not be a difficulty. From the crucible steel maker's point of view that question had to be considered rather carefully.

Mr. E. H. SANITER (Vice-President) said the only point on which he hoped the author would throw further light was with regard to the regulation of the temperature during casting.

Mr. L. ROTHERA (Stafford) mentioned that the development in high-frequency electric furnaces of considerable power had been dependent, to some extent, on a corresponding development in electrical machinery. Electrical machines designed for 500 cycles presented no great difficulty, but when much higher frequencies were required special problems, both electrical and mechanical, were introduced; and the manufacture of such machines was of comparatively recent date. His firm had recently completed two such machines for the author and were at the present time building a third, the unit consisting of a motor-generator set running at 3000 r.p.m. with an output of 150 kw. The satisfactory construction of such machines which could be used direct on the furnace rendered unnecessary the complicated and fragile spark gaps which had hitherto been used, and made the process described by the author a practical steelworks proposition.

Mr. CAMPBELL, in reply, said that he supposed Professor Desch had used the words "convection currents in the steel" as a general

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term, which meant the violent disturbance due to convection and movement caused by the electrical field, as the movement was principally due to the latter cause. He had recently carried out some interesting experiments in that connection, because it was supposed by some that that violent movement would cause oxidation to an excessive degree. Aluminium foil or paper in large quantities had recently been melted, and it was interesting to see that the surface of the metal would rise about $1\frac{1}{2}$ in. in the centre of the crucible, taking almost a spherical form. In the case of aluminium the oxidation loss was very low as compared with existing practice, because the curved surface was covered with a thin skin of oxide; in the case of steel, similar protection could be obtained by slag.

Professor Desch had mentioned that when a crucible cracked it did not matter, because the metal was held up by the backing behind it. That was frequently the case, but if the crucible cracked before the backing had had time to get fritted against the crucible, the metal sometimes went through the bottom; the damage was not, however, excessive. In his experience several lots of 300 or 400 lb. of steel had broken out of crucibles. It sometimes ran against the coil, but it was immediately chilled against it; it could usually be removed without damage to the coil, but if not there was no difficulty in cutting one spiral out of the coil and soldering in a new one, because, as the temperature never exceeded 80° C., high-temperature brazing was not necessary. If a crucible broke badly the damage usually was limited to the loss of metal, and about a quarter of an hour's delay if a spare body were available for insertion, and a couple of hours' work to repair the coil and set up another crucible. The spare body consisted of a wooden box having a coil and water connections and an insulated sleeve, so that it was a very small matter to keep a spare body ready. In no case had any serious short circuits occurred such as to damage the electrical equipment in any way.

Mr. Saniter had asked a question with regard to the temperature of casting. In the furnace to which he referred any temperature that was required could be obtained, provided the crucible or container would stand it. Manganese, for example, could be distilled. The difficulty was to measure those high temperatures. As in every other matter of a similar kind, a certain amount of skill was required to make steel commercially, but it had been found that the temperature could be exceedingly well controlled and determined by methods used with arc furnaces. The melter controlled his input of heat by a rheostat; he could reduce his load better than he could with an arc furnace, because the rheostat had many steps allowing him to vary his load to any extent, whereas with an arc furnace there were usually two alternative voltages, and it was necessary to work by raising the electrode. Very low loads thus involved longer arcs, which were objectionable, so that arc furnaces were not always as easy to control as the high-frequency furnace.

Mr. Rothera had referred to the electrical equipment. The plant contained only one moving part, namely, the motor-generator; the condensers were merely tanks of oil containing packets of tissue paper and tin or aluminium foil. There were a few controlling instruments, and that constituted the whole installation, so that the risk of breakdown and the maintenance cost were low. He thought, therefore, it could be said that the equipment was one that could be put into any works with confidence that it would be maintained in regular operation.

In reply to the President's inquiry, Mr. Campbell said that, apart from metallurgical variations, and dealing only with the question of temperature, a charge of 300 or 400 lb. of hot metal well covered with slag could be kept hot without difficulty for at least ten minutes, but the load could be put on to heat the charge again if it were found to be too cold. That would not apply to Professor Desch's experimental and laboratory plant, where only 10 to 15 lb. of metal were dealt with. The heat insulation was often exceptionally good, but it varied according to the nature of the insulating sand that was used. They were working partly with plumbago crucibles for high-speed steel, and were also using carbon-free clay crucibles for such operations as remelting stainless iron and steel and low-carbon alloys. If a large number of very small castings were being poured, the furnace body could be taken away and used as a small casting ladle and another put in position and a charge melted while the first was being poured.

THE BEHAVIOUR OF MILD STEEL UNDER PROLONGED STRESS AT 300° C.¹

By W. ROSENHAIN, D.Sc., F.R.S., AND D. HANSON, D.Sc.
(NATIONAL PHYSICAL LABORATORY).

ABSTRACT.

In connection with the study of intercrystalline cracking in boiler plates, prolonged exposure tests under loads ranging from one-third to two-thirds of the normal ultimate stress have been carried out in air at a temperature of 300° C., which has been maintained almost uninterruptedly for over five years. The material used was a mild steel strip containing 0·106 per cent. of carbon, a trace of silicon, and 0·395 per cent. of manganese with very low impurities, and test-pieces in various conditions of heat treatment were employed. In no case did fracture occur, and only in one of the most heavily loaded test-pieces did any appreciable stretching take place. The Brinell hardness of the steel, however, increased to a marked extent in the stressed portions of the test-pieces, and this result is regarded as remarkable in view of the small amount of deformation which the steel underwent.

THE experiments described in this paper arose out of certain investigations into the cracking of mild steel exposed to elevated temperatures, particularly the cracking of steel boiler plates. Mysterious cases of boiler failure occur from time to time through the development of fine cracks in the neighbourhood of the rivet holes. These cracks usually develop at the contact surfaces of the plates along the riveted joint, and are definitely intercrystalline in character. Various suggestions have been made to account for this cracking, and, in particular, for this intercrystalline character. The view most generally accepted is that it is due to a combination of chemical attack with the application of severe local stresses.

It is clear from the manner in which these cracks are formed that they develop very slowly in the steel, and it is therefore of importance to ascertain the effect of the prolonged application

¹ Received July 21, 1927.

of stresses on mild steel at temperatures in the neighbourhood of those to which boilers are subjected. Only when this information is available would it be possible to arrive at a correct understanding of the combined effect of stress and chemical attack.

The experiments which the authors have undertaken have been devised in order to determine the effect of prolonged application of stresses to mild steel at a temperature of $300^{\circ}\text{C}.$, particularly with a view to determining whether stresses well below the normal tensile strength will cause failure if applied for a very long time. For this purpose small test-pieces of rolled mild steel strip¹ have been subjected to tensile stresses of approximately one-third, one-half, and two-thirds of the breaking stress, the load being applied by means of short levers having a ratio of approximately 8 to 1. The whole of the mechanism was enclosed in a large electrically heated oven, which could be maintained at the selected temperature, $300^{\circ}\text{C}.$, for a long period.

In the investigation of a number of failures of mild steel by intercrystalline cracking, attempts have been made to determine whether any particular structure of the steel corresponding to some definite form of heat treatment is associated with this type of failure. No definite conclusions could be drawn from these observations, although the largest number of cases of failure was found in steel plate in which the cementite had been segregated between the boundaries of the ferrite crystals. In other instances, however, a pearlitic structure was observed, and in still another case the cementite existed as fine globules scattered throughout the ferrite grains. In order to ascertain if the structure of the steel had any influence on its behaviour, different batches of specimens were subjected to appropriate heat treatment, with a view to securing the above three types of structure, while a fourth series was tested in the cold-rolled condition. Figs. 1, 2, 3, and 4 (Plates IV. and V.) show the structures of the steel test-pieces before testing. Fig. 1 represents specimens heated to $900^{\circ}\text{C}.$ and cooled very slowly, particularly over the range of temperature from $720^{\circ}\text{C}.$ to $650^{\circ}\text{C}.$, and consisting of ferrite grains with intercrystalline films of cementite. Fig. 2 shows the normalised test-piece, and possesses the structure characteristic of normalised

¹ The composition of the steel used is as follows : Carbon 0.11, silicon trace, sulphur 0.075, phosphorus 0.050, and manganese 0.395 per cent.

TABLE I.

Mark No.	Treatment.	Microstructure.	Before Test.		After Test.		Load Applied.		Maximum Tensile Strength of Material. Tons per sq. in.	Remarks.
			Width. In.	Thickness. In.	Width. In.	Thickness. In.	Actual. Kg.	To: s per sq. in.		
A9) A10) A11)	Heated to 900° C.; slowly cooled from 720° C. to 650° C.	Free cementite in boundaries of ferrite crystals	{ 0.1010 0.1009 0.1005 }	{ 0.0203 0.0205 0.0205 }	{ 0.1005 0.0998 0.0994 }	{ 0.0196 0.0202 0.0199 }	{ 10.0 15.0 20.0 }	{ 5.0 7.5 10.0 }	{ 15 }	...
A14) A15) A16)	Normalised at 900° C.	Ferrite - pearlite (small structure)	{ 0.1000 0.1002 0.0750 }	{ 0.0207 0.0204 0.0204 }	{ 0.0997 0.0992 0.0714 }	{ 0.0200 0.0198 0.0198 }	{ 14.0 22.0 22.5 }	{ 7.0 11.0 15.0 }	{ 22.5 }	Visibly stretched in oven
A32) A33) A34) A36)	Cold-worked and annealed for four days at 650° C.	Ferrite + globular cementite	{ 0.1006 0.0998 0.1002 0.0999 }	{ 0.0195 0.0204 0.0213 0.0200 }	{ 0.1002 0.0993 0.1002 0.0995 }	{ 0.0195 0.0197 0.0220 0.0200 }	{ 10.0 15.0 10.0 20.0 }	{ 5.0 7.5 5.0 10.0 }	{ 15 }	Coated with solder
A37) A38) A39)	As cold-rolled	Large distorted ferrite grains	{ 0.0995 0.1000 0.0750 }	{ 0.0195 0.0203 0.0200 }	{ 0.0995 0.1000 0.0749 }	{ 0.0193 0.0199 0.0200 }	{ 16.0 24.0 24.0 }	{ 8.0 12.0 16.0 }	{ 24 }	...

mild steel. Fig. 3 shows the structure of samples annealed for four days at 650° C. after cold-working, this material consisting of ferrite grains throughout which the cementite is distributed in the form of small globules. Fig. 4 shows the elongated grains of the cold-worked material, the cementite being distributed, in this sample also, as globules throughout the ferrite grains. Table I. shows the test-pieces used, their heat treatment and structure, the dimensions both before and after testing, the maximum tensile strength of the material, and the loads applied during the prolonged tensile tests. The ultimate stress of the material was determined in each instance on small test-pieces similar to those used in the main experiments. The heat treatment was applied in all instances after the test-pieces had been cut, with a view to avoiding any cold-working effects at the edges of the test-pieces during preparation. In addition to the specimens described above, one test-piece was included which had been coated with solder over the parallel portion, with a view to testing whether any acceleration of the failure could be observed owing to the action of the solder, which would be liquid at the temperature of the test.

The specimens were placed in the straining apparatus, which was contained in the large oven previously mentioned, the loads were applied, and the oven raised to 300° C., at which temperature it was maintained. The specimens were examined from time to time, to observe their behaviour. Appreciable stretching of the test-pieces could easily be detected by the movement of the lever through which the load was applied. Only in one instance, specimen A16, tested as normalised under a stress of 15 tons per sq. in., did any appreciable elongation occur during the period of the test. The tests were continued over a period of five years and three months, during which time the loads were maintained continuously and the furnace was allowed to cool to room temperature upon two occasions only, in each case only for one or two days. None of the specimens broke, and at the end of this long period the test was discontinued and the specimens were removed for examination.

During the course of the prolonged heating the specimens oxidised but slightly, passing through the usual range of temper colours and finally assuming a grey appearance. The thickness of the film produced was inappreciable. The specimens were

carefully measured before and after the test, but since it was initially expected to make only observations of the breaking strength, gauge marks were not put on the parallel portions, and no figures for elongations could be obtained. The measurements of the width and thickness of the test-pieces, before and after test, give an indication of the flow of the material, which, as the figures in Table I. show, has been very slight in every instance.

In order to ascertain whether any change had taken place in the material as a result of the prolonged loading, the specimens were examined for Brinell hardness and microstructure. Brinell hardness tests were made on the material of the parallel portion subjected to maximum stress, and also on the material above the shoulders, which had been subjected to a very small stress only, but which had undergone the same prolonged thermal treatment at 300° C. The results of Brinell tests are shown in Table II.

TABLE II.—*Brinell Numbers taken on the "Strained" (Centre) and "Unstrained" (Shoulders) of the Test-Pieces at the Conclusion of the Test.*

Mark No.	Brinell Number.	
	Centre.	Above Shoulders.
A9	72.0	59.0
A10	73.5	50.3
A11	83.0	51.0
A14	85.0	71.0
A15	87.0	69.6
A16	97.0	70.0
A32	79.0	66.0
A33	83.8	62.0
A34	87.0	58.0
A36	107.0	64.0
A37	145.0	127.5
A38	135.0	127.5
A39	142.0	128.0

5-kg. load and 1-mm. ball. Experiments started Sept. 1920, stopped Dec. 1925.

A 1-mm. ball was used under a load of 5 kg. The results of these tests disclose in all instances a remarkable hardening of the material in the parallel portions of the test-pieces, this hardening being appreciable even in specimens which had been subjected to

a stress of only one-third of the normal breaking stress. The degree of this hardening is astonishing, in view of the fact that the actual extension of the material under test is very slight; in the case of specimen A16, in which visible stretching occurred in the oven, the extent is estimated to be not greater than 3 per cent.; in the other test-pieces the extent was very much less than this. The results seem to indicate that the application of a prolonged load, resulting, no doubt, in slight gradual straining of the metal, has a very profound effect on the hardness—an effect which is much greater than would be anticipated from the actual amount of work, measured by the change of length, to which the material has been subjected. This hardening has no doubt played an important part in increasing the resistance of the material to stress and in preventing its failure under the prolonged action of the applied loads.

The microstructure of the specimens has also been examined in the highly stressed region after the test. Micrographs are shown in Figs. 5 to 8 (Plates IV. and V.), their order being the same as that of the specimens examined before testing. No changes in microstructure due to the action of stress and temperature could be observed.

CONCLUSIONS.

The experiments show that samples of mild steel, subjected to various forms of heat treatment, are capable of withstanding severe stresses up to two-thirds of the normal breaking stress, for prolonged periods at 300° C. In the present tests these stresses have been withstood for over five years, and it seems likely that the steel will withstand such stresses indefinitely. The experiments show that steel subjected at 300° C. to stresses between one-third and two-thirds of the normal breaking stress became considerably hardened, although the amount of straining is very slight. In the experiments described above, however, the stress has in every instance been uniform throughout the cross-section of the small test-piece. Localised stress, such as that due to a notch, may give different results, and similar experiments with notched test-pieces are in progress.

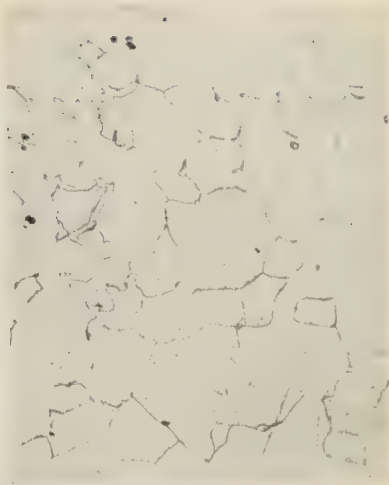
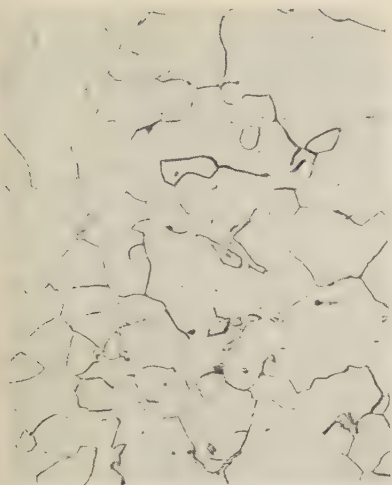


FIG. 1.—Structure of specimens heated to 900°C . and cooled very slowly, particularly from 720°C . to 650°C . Ferrite grains with inter-crystalline cementite films.

FIG. 5.



FIG. 2.—Normalised test-piece. Structure characteristic of normalised mild steel.

FIG. 6.

Figs. 1 and 2.—The structures of the test-pieces before testing.

Figs. 5 and 6.—The structures of the same test-pieces after testing.



FIG. 3.—Sample annealed for four days at 650° C. after cold-working. Ferrite grains with cementite distributed throughout as small globules.



FIG. 7.



FIG. 4.—Cold-worked material, showing elongated grains; cementite distributed as globules throughout the ferrite.



FIG. 8.

Figs. 3 and 4.—The structures of the test-pieces before testing.

Figs. 7 and 8.—The structures of the same test-pieces after testing.

DISCUSSION.

Mr. C. E. STROMEYER, O.B.E. (Manchester), said the subject with which the paper dealt was an exceedingly important one. As the members were aware, he had personally devoted a good deal of his attention to discovering the reasons why steel plates cracked every now and then. He had published a paper in the previous year, in which he called attention to the fact that amongst a large number of failures there were a good many cases for which he had been able to discover the reason, but for thirteen failures he could offer no explanations. There was little phosphorus, little nitrogen, little carbon, and no chance of caustic embrittlement. He was now doing his best to discover the cause of the brittleness in those thirteen plates, but it was not quite as simple as the authors seemed to think. Some of the failures were in the centres of the plates. They did not start at the rivet holes, but there were little patches of brittleness in the steel. He hoped some day to be able to throw some light on the subject, but that day was not yet.

He wished to deal with some of the results given in the paper. He had analysed Table II., which was really the essential part of the paper, by grouping the relative results in the order of stresses, taking the Brinell test at the end of each sample as the unit of comparison. Those relative results for the five groups were 1.24, 1.28, 1.52, 1.06, and 1.25. The average of numbers 3 and 4 was 1.29, and the average for the whole was 1.27. Practically the ratios were the same in all those cases, but interest attached to the contrast between the effect of the 5-ton stress as compared with that at the ends of the samples, and the absence of any further effect for higher stresses. That was an exceedingly interesting point which he hoped the authors would follow up. He would also like the authors to make an additional practical test, but of course they could not make it on one test-piece only. He would suggest that they bend the present test-pieces with the object of seeing whether they were more brittle than they were originally. From an engineering point of view that was information he would very much like to possess, for in boilers there were many chances of the material being stressed beyond its elastic limit for long periods at a time but without serious effect on ductility. Furnaces gradually became more oval but remained ductile, and water-tubes swelled and possibly burst, but could then be bent double. A Stirling tube recently came into his possession which had seven bulges due to overheating, and yet it was ductile. The bulging was suspected to have been due to the density of the water. That tube had been sufficiently hot to stretch under pressure. A good many cases occurred in which boiler tubes stretched which were exaggerated cases compared with those experimented upon in the present instance, and yet the steel was as mild and

ductile as before. In some of those cases he noticed after etching by the Fry method that there were a number of lines which indicated shearing stresses. A continuation of the work described in the paper might throw some further light on those problems.

Mr. E. H. SANITER (Vice-President) asked if the figures in Table II. were Brinell numbers, or whether they were comparative numbers between the two pieces. For instance, the 59 Brinell number gave a tensile strength of only 14.75 tons per sq. in., and personally he had never heard of any iron or steel out of which it was possible to get only 14.75 tons.

Mr. J. H. WHITELEY (Saltburn-by-the-Sea) congratulated the authors on their patience in carrying out experiments extending over a period of five years. The sample of steel which they had chosen to experiment with was not exactly typical of boiler plate. Makers were not supposed, for instance, to make boiler plates with 0.075 per cent. of sulphur, while the carbon and the manganese were too low. In his opinion, the steel was inferior to boiler plate steel, but of course that did not affect the results. If such steel stood up to the prolonged test, he had no doubt that boiler steel would do the same. The tests were particularly interesting because they had been made at about 300° C., which was about the "blue-heat" temperature. As was well known, steel worked at that temperature was liable to be brittle. Test-pieces sheared off a plate at blue heat frequently snapped on bending, although if they were sheared cold they bent easily. As Mr. Stromeier had said, it would be interesting if the authors tried a bend-test on some of the pieces. The conditions of the experiment were not exactly those which obtained in service. He thought it must be admitted that a boiler in use was subjected to a certain amount of vibratory stresses due to the ebullition of the water. Then there was always some degree of localised cold-work in a boiler plate. Even if the plates were planed instead of sheared and the rivet holes drilled, the riveting itself introduced a certain amount of localised cold-work. Those conditions were not present in the experiments.

He would make a statement which, he wanted it clearly understood, was put forward purely in the interests of the discussion of the paper. It was that in his long experience of the manufacture of boiler plates, during which he had seen and supervised the manufacture of many tens of thousands of tons of both acid and basic quality, he had never yet met with a failure in service. He was quite certain if any plate had failed he would have heard about it. Yet he knew that other firms making steel plates had had serious trouble. He had one case in mind of a works making plates by the same process as they did, and with practically the same material, where, after shearing two adjacent sides of a plate, the corner would sometimes drop off. Some time ago such a sample was sent to him, but after an exhaustive

examination he had not been able to discover why the failure occurred ; he could find no indication of the cause of the brittleness under the microscope. He believed it was produced somewhere between the ingot stage and the finished product, but could not say definitely where. If the authors or anyone else could enlighten him on that point, he would be greatly obliged.

Dr. W. H. HATFIELD (Member of Council) said that he had read the paper with interest, and was gratified in a broad sense with the results disclosed. It must not be forgotten that at the time when the authors put their experiments in hand from five to seven years ago, it was actually asserted by some investigators that steel and other metals exposed at temperatures a little above the normal would fail over long periods of time at very small stresses. The authors then commenced the tests described, and after five years' investigation the results were given in the paper. It was quite clear that steel might be stressed to very high values at 300° C., 400° C., and, it had been found elsewhere, at even slightly higher temperatures, without a chance of failure when the stresses were left on for a long time. That was a point of very great importance to engineers. On the other hand, there were a few points he desired to make. For instance, the authors said that "the view most generally accepted was that the failure of boiler plates was due to a combination of chemical attack with the application of severe local stress." Surely that was not the general view held. Those people who were best in a position to give an opinion on such failures were very clear in their own minds as to what was the cause of failure. If a mild steel boiler plate failed in the manner which the authors were considering, it was due almost certainly to some minor mechanical defect at the outset of service introduced in the course of manufacture, either minute cracks produced in the holes during preparation, as clearly disclosed by Dr. Stead many years ago, or as the result of local cold-working. The outcome of the publication of the authors' research would be to give a little more confidence, if it were needed, to engineers in the use of higher pressures and temperatures in boiler work. Referring to the maximum stress of 15 tons per sq. in. obtained by the authors from a boiler plate, surely that value was too low. He would be surprised if steel of the analysis disclosed at the bottom of p. 118 gave a lower value under any conditions than 20 or 21 tons per sq. in., and even that would be extremely low. He also desired to emphasise Mr. Saniter's remarks with regard to Table II. If those figures could be substantiated, the effect of introducing hardness by exposure to 300° C. would provide very interesting new data. It must not be overlooked (and that was not pointed out in the paper) that at the temperatures at which the authors were carrying out their experiments, namely, 300° C., steel or iron which had a tensile strength of 22 to 23 tons per sq. in. actually possessed at a temperature of 300° C. a tensile strength of 30 tons per sq. in. That had been confirmed by several investigators, and therefore

should be taken into consideration when the stresses which they were imposing upon the material at that temperature were being considered.

There was only one other thing he desired to say; he said it with a little fear, and he hoped it would not be construed in a wrong way. When the National Physical Laboratory or any such Institution proposed to investigate problems such as those dealt with in the paper, which were of great value to all the members, he hoped they would go to some responsible people in the industry, inform them that they proposed to carry out the investigation, and ask them to supply some really good material, because he was sure that that would enhance the value of the results when they were ultimately published. For instance, as Mr. Whiteley said, the analysis at the bottom of p. 118 was not typical of British boiler plates, and he was sure it was not the material which was being used at present for the extremely complex technical propositions which had to be dealt with from the high pressure point of view.

Mr. E. A. ATKINS (Warrington) said he desired to ask only two questions. In the first place, he would like to know if the authors thought the results would have been exactly the same if the tests had been carried out with variations of temperature from, say, 100° to 300° C. In the second place, he desired to ask whether they did not consider that type of steel, the microstructure of which was shown in Fig. 1, would not be in an extremely dangerous state if it happened to be used in a vessel under pressure subject to vibration, seeing that the grain boundaries contained crystallised cementite.

The AUTHORS, in a joint reply, thanked the various speakers for their contributions. Mr. Stromeyer had referred to the hardening of the steel when subjected to stress at 300° C., and had suggested that that hardening might be accompanied by serious embrittlement. The authors had been unable to test that point, but could say that the test-pieces were not so brittle that they could not be very readily bent after their long exposure. It was clearly impossible, with such small specimens, to carry out any of the standard tests for brittleness. As Mr. Whiteley pointed out, the steel used was not that generally regarded as most suitable for boiler plates, but it was unnecessary to use steel made to boiler-plate specifications for the particular purpose that the authors had in view. Intercrystalline cracking was not confined entirely to steels made to boiler-plate specification, and for a general investigation of this kind any ordinary grade of mild steel, particularly when it was heat-treated in a variety of ways as in the authors' experiments, could be regarded as suitable. In any case, as Mr. Whiteley said, if the authors' steel would stand such prolonged tests, there was little doubt that boiler steel would do the same. Dr. Hatfield had objected to the statement made by the authors, that the view most generally accepted was that intercrystalline cracking of boiler plates was due to a combination of chemical attack with the

application of severe stress. The authors believed that that was the view most generally accepted at the present time. In their opinion minute cracks produced in the rivet holes during preparation, and local cold-working, certainly played a part in those cases of failure, but the authors were not satisfied that such features could account for the peculiar intercrystalline cracking, amounting in many cases to local disintegration of the material. A crack produced under the action of stress alone was usually, though not necessarily always, transcrystalline. The authors wished to preserve an open mind on that point, but the bulk of the experimental evidence at present available certainly suggested that in most of the known cases some chemical attack was necessary. The authors were well aware that at a temperature of 300° C. the tensile strength of steel was definitely greater than at room temperature; having regard to that fact, the hardening obtained in the authors' experiments was all the more remarkable and important. Dr. Hatfield's criticism of the material used was answered in the reply to Mr. Whiteley. With regard to the remarks made by Mr. Saniter and Dr. Hatfield concerning the mechanical properties of the steel, he desired to say that the tests carried out could hardly be regarded as standard mechanical tests. The steel was both used and tested in the form of very thin strip; the results should therefore be taken as only comparative values. The same remark applied to the Brinell numbers. They were not made with the standard load at all, and it was therefore not to be assumed that the tensile stress could be calculated from these hardness numbers as they could be from the standard test results.

THE CONSTITUTION OF SILICON-CARBON-IRON ALLOYS AND A NEW THEORY OF THE CAST IRONS.¹

BY PROFESSOR D. HANSON, D.Sc. (BIRMINGHAM).

INTRODUCTION.

THE importance of a correct knowledge of the relationships between the various constituents of metallic alloys has been recognised now for many years, and in no instance is this knowledge of greater importance than in the alloys of iron and carbon. The constitution of the carbon steels, and its relation to their behaviour during casting, annealing, and heat treatment, is well understood, and the metallurgy of steel now rests on a very substantial scientific foundation. In the case of the other important series of iron-carbon alloys, known as the cast irons, the position is not so satisfactory. These materials are more complicated, both in regard to structure and composition, than are the steels, and although numerous investigations have given a large amount of information about them, a satisfactory comprehensive theory of the cast irons has not yet been evolved. Structurally the cast irons differ essentially from the steels in that the carbon can exist, and usually does exist, in two forms, iron carbide and graphite, and the main problem requiring solution is the definition and explanation of the relations between these two forms of carbon in the alloys. The theories which have been advanced, of which the most generally favoured is the "double-diagram theory," are admittedly incomplete and unsatisfactory.

Cast iron is by no means a simple alloy of iron and carbon ; it contains considerable amounts of other elements—silicon, phosphorus, sulphur, and manganese—each of which is known to have an important influence on the alloy.

The British Cast Iron Research Association, recognising the importance of a fuller knowledge of the influence of these elements in

¹ Received June 10, 1927.

cast iron, has initiated a series of researches on the ternary alloys of iron and carbon at the National Physical Laboratory, under the general supervision of Dr. W. Rosenhain, F.R.S. The first of these investigations—into the alloys of iron and carbon with silicon—was entrusted to the author, and the results so far obtained are now described, with the kind permission of the British Cast Iron Research Association.

The experimental work was interrupted upon the author's appointment to another post, and it is, in certain respects, incomplete, and is insufficient to enable the complete equilibrium model to be constructed. Certain important conclusions can, however, be drawn, and appear to justify publication at this stage.

EXPERIMENTAL DETAILS.

The experiments described below have had as their object the determination of the constitution of pure silicon-carbon-iron alloys, over the range of composition 0 to 2 per cent. silicon, 0 to 4 per cent. carbon ; this range was chosen, not so much with a view to approximating commercial cast irons, as to investigating the range most likely to lead to conclusions of theoretical importance and to test certain hypotheses relating to the nature of cast irons, to which reference is made below.

Preparation of Alloys.—The alloys were made from electrolytic iron, pure silicon, and Acheson graphite. These are pure materials, only traces of any impurity being present, except oxygen in the electrolytic iron, which was reduced and removed during the preparation of the alloys. Chemical analyses are given in Table I. :

TABLE I.—*Analyses of Materials.*

Material.	Fe. %	Si. %	C. %	O. %	Al. %	Ca. %	Cu. %	All Other Impurities.
Electrolytic iron	99.79.	...	0.006	0.2	...	...	Traces	0.004
Silicon .	0.04	99.8	...	...	0.03	0.024	...	0.10
Graphite .	Trace	Traces	99.9	...	...	...	...	0.1

In order to simplify the process of alloying, two stock alloys were made :

1. A 20 per cent. silicon-iron alloy (composition by analysis, 22.86 per cent. silicon). This was made by melting together silicon and iron in a crucible of fused magnesite in a high-frequency induction furnace : a nitrogen atmosphere was employed.

2. A high-carbon iron alloy, to which a little silicon was added to ensure its remaining grey, in which form it could readily be cut for weighing out. It was prepared as in the case of the silicon alloy, except that a crucible of Acheson graphite was used, the iron being allowed to dissolve as much carbon as possible. The chemical analysis of this stock alloy was silicon 0.93, carbon 6.83, and iron 92.20 per cent. A series of eighteen alloys, containing 0 to 2 per cent. silicon and 0 to 4 per cent. carbon, was made, using the stock alloys. The materials were carefully packed in a crucible of fused magnesite and placed in a high-frequency furnace ; the furnace was evacuated to a pressure of about 1 mm. mercury gauge, which was maintained during melting.¹

When first melted the alloy bubbled vigorously, owing to reaction between the oxygen in the iron and the carbon. The melt was kept liquid until no more gas bubbles were given off, which was ascertained by looking through a window in the top of the furnace, and the alloy was then cooled in the furnace tube. The ingots, which were generally sound, were cleaned and weighed, the average loss during melting, from various causes, being 1 to 2 per cent. About 150 grm. of each composition was made.

Cooling Curves.—Cooling curves were obtained by remelting 40 to 50 grm. of alloy in a crucible of fused alumina ; a carbon-ring furnace was used, into which a stream of nitrogen was passed. The atmosphere inside such a furnace is very harmful to platinum thermocouples, and special precautions must be taken if reliable temperature readings are to be obtained. In the present instance the crucible was contained in a glazed muffle, closed at one end, which fitted into the tube of the furnace. A 5 per cent./20 per cent. platinum-rhodium thermocouple was used, it having been found that this combination, which is only slightly less sensitive than the standard 0/10 per cent. thermocouple, deteriorates much

¹ A graphite lid on the crucible was very effective in preventing "bridging" or "scaffolding" of the melt, and did not increase the carbon content.

less rapidly in reducing atmospheres. The thermocouple was encased in a thin-walled silica sheath, closed at one end, which was lowered into the molten metal. Silica becomes very soft at the high temperatures used, and the sheaths would not support their own weight if allowed to rest on the bottom of the crucible; they were therefore supported from the cold end in such a manner that the bottom end of the sheath and the junction of the couple did not quite reach the bottom of the crucible. The sheath was maintained centrally in the crucible, and was prevented from warping in the hot zone by passing it through a central hole in a very deep crucible lid. The thermocouple was calibrated frequently by determining the melting point of pure iron, and the error was seldom more than 5°C. at 1500°C.

Inverse rate curves were taken on a Rosenhain plotting chronograph; the arrest points are tabulated in Table II., and plotted in Figs. 1, 2, and 3.

TABLE II.—*Arrest Points and Composition of Alloys.*

Alloy.	Freezing Point. $^{\circ}\text{C.}$	Eutectic Point. $^{\circ}\text{C.}$	A_4 . $^{\circ}\text{C.}$	A_3 or A_c . $^{\circ}\text{C.}$	A_2 . $^{\circ}\text{C.}$	A_1 . $^{\circ}\text{C.}$	Composition.		Remarks.
							Carbon. %	Silicon. %	
SC2	1507	...	1476	754	667	632	0.31	0.48	A_1 very small
SC3	1503	...	1457	738	...	686	0.36	0.93	
SC4	1481	...	1433	760	...	686	0.33	1.89	
SC5	1514	...	1457	795	...	...	0.18	0.44
SC6	1509	...	1457	774	...	680	0.12	1.04	
SC7	1453	...	1419	...	...	714	0.66	1.88
SC8	1438	...	...	...	...	694	1.08	0.40
SC9	1453	...	...	754	...	694	0.82	0.95
SC10	1427	...	...	...	...	731	1.00	1.97
SC11	1390	(1100 ?)	1354 (?)	982	...	708	1.88	0.33	
SC12	1419	...	1346 (?)	(?)	...	725	1.41	0.79	
SC13	1417	1188	...	989	...	760	1.39	1.77	
SC14	1285	1115	...	...	...	709	2.82	0.39
SC15	1306	1135	...	...	...	725	2.70	0.89
SC16	1276	1140	...	...	...	754	2.73	1.90
SC17	1190	1105	...	...	...	716	3.61	0.39
SC18	1194	1145	...	...	...	725	3.55	0.83
SC19	1200	1131	...	...	...	731	3.21	1.88

A separate chemical analysis was made of each cooling curve ingot. Brinell hardness measurements were also made on each ingot, and the figures obtained are given in Table III.

TABLE III.—*Brinell Hardness Numbers (Cooling Curve Ingots).*

Constant Silicon. 0.4%		Constant Silicon. 0.9%		Constant Silicon. 1.9%	
Alloy.	Brinell No.	Alloy.	Brinell No.	Alloy.	Brinell No.
SC5	135	SC6	156	SC7	227
SC8	230	SC9	242	SC10	261
SC11	283	SC12	260	SC13	266
SC14	224	SC15	246	SC16	213
SC17	...	SC18	153	SC19	171

Sections through the ingots were polished and examined microscopically; a representative series of micrographs is shown in Figs. 17 to 25 (Plates VI. and VII.).

Heat Treatment of Alloys.—A consideration of the microstructures of the alloys, in relation to the cooling curves obtained, shows quite clearly that equilibrium was not obtained in the cooling curve ingots. A series of heat-treatment experiments was therefore undertaken with a view to elucidating the equilibrium structures of the alloys.

In view of the high temperatures involved in work of this kind, and of the long periods of heating that are necessary, special precautions have been taken to avoid oxidation of the small specimens necessarily employed. Heating was carried out by inserting the specimens in a tube of clear quartz, closed at one end, and connected through a rubber bung with a good vacuum pump capable of maintaining a pressure of the order of 0.001 mm. This tube was placed in a specially constructed electric furnace wound with "bright-ray" wire, and capable of withstanding a temperature of 1150° C. for long periods. The furnace was so wound that the temperature of a length of several inches in the centre did not vary more than 1° or 2° C. This furnace proved very satisfactory in use; it was heated several times to about 1200° C., and for a total of several weeks between 1000° and 1150° C., and it was in use continuously for a period of over six months without showing any sign of deterioration.

The clear quartz tube was inserted in this furnace so that the specimens were in a uniformly heated zone; temperatures were measured by means of a thermocouple placed inside the furnace

but outside the quartz tube, and connected to a thread recorder, by means of which a continuous record was taken. This record was used to check the constancy of the apparatus, and actual temperatures were measured on a sensitive potentiometer and checked at short intervals during all experiments.

In all instances specimens were annealed for a considerable time at about 1150°C. , in order to obtain equilibrium at that temperature, and were then cooled very slowly to successive lower temperatures, from which they were quenched, and examined under the microscope. The furnace was controlled throughout, both during heating at a constant temperature and during the slow-cooling experiments, by means of a thermostat.

Small specimens cut from the original ingots were treated several at a time. The period of heating at the high temperature varied from several hours to two days, and the rates of cooling were usually of the order of 100° to 200°C. per day. Specimens were usually held for some time at a constant temperature before being quenched in water. The total time taken for any experiment was usually about one week.

(Details of the various alloys, their heat treatment and the structures observed, are given in an Appendix, and are represented micrographically in Figs. 26 to 40, Plates VII. to IX.)

The pressure in the apparatus was measured from time to time by means of a sensitive McLeod gauge. When the silica tube was heated to a temperature of about 1100°C. the pressure obtainable was between 0.014 and 0.02 mm.; as the temperature was reduced so the pressure attainable fell; and for all temperatures below 850°C. a pressure of 0.001 to 0.002 mm. could be maintained. The vacuum pump was, however, not normally left running over-night, and the pressure rose gradually through this period, sometimes to as much as 1 cm.

None of the specimens showed any signs of oxidation after heat treatment, but some exhibited a curious feature which necessitated the use of new specimens for each treatment. In certain instances it was observed that the interior of the specimen appeared to have been decarburised; it was then found that the surface of such specimens was almost covered with a number of small black nodules, which, upon investigation, were found to be graphite. This migration and precipitation of graphite on the

surface of certain specimens is noted in the Appendix, and was taken into consideration when dealing with the microstructure of the alloys concerned. It was thought that this phenomenon might be due to the presence of gas in the tube, and that the equilibrium of the system might be disturbed by the presence of this gas. Some check experiments were therefore made, in which the vacuum pump was kept running continuously, day and night, thus maintaining a high vacuum throughout the experiment. This treatment was successful in preventing the migration of graphite, but the constitution of the alloys did not appear to differ in the two cases.

In order to avoid possible errors due to surface effects, practically all specimens were cut through the middle, the cut surfaces being polished; in any case in which a structure was considered to be doubtful repeat heat treatments were made.

DISCUSSION OF RESULTS.

Cooling Curves.—From the cooling curves it is possible to construct diagrams indicating the transformations occurring in the three series containing 0.4, 0.9, and 1.9 per cent. of silicon, and such diagrams are shown in Figs. 1, 2, and 3 respectively.

The liquidus curves are well defined, as is also the arrest due to the transformation of δ - to γ -iron. The temperature of this transformation is higher than in pure iron, but lower than in pure iron-carbon alloys, and extends over a wider range of carbon concentrations as the silicon content is increased.

The eutectic arrest *CE*, which is well defined, is clearly due to the austenite-graphite eutectic: this is definitely established by the microstructures; Fig. 26, in particular, shows clearly primary austenite grains embedded in a very fine matrix of austenite-graphite eutectic. This structure is similar to that obtained by Piwowarsky in his superheated cast irons. No evidence was obtained of the prior formation of the austenite-cementite eutectic; there was but one heat evolution on the cooling curves. If graphite were formed only from cementite, two heat arrests should be observed, one corresponding to the formation of the austenite-cementite eutectic, and the second to the decomposition of the carbide. The possibility of graphite forming through cementite

is not denied, since under certain conditions it has been proved to occur, but in the present experiments there appears to be no doubt that graphite separated direct from the liquid as one of the constituents of the eutectic.

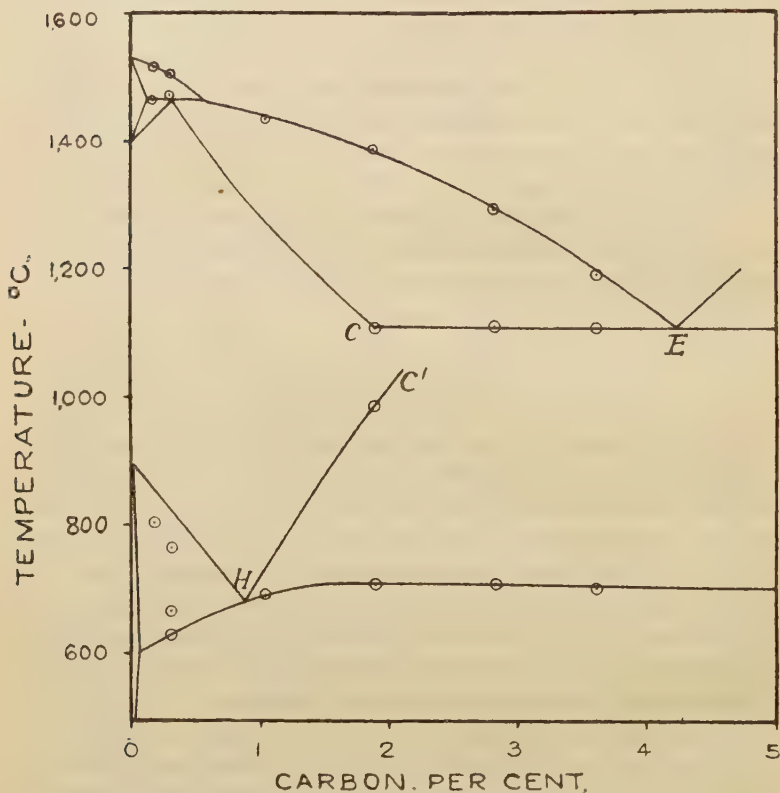


FIG. 1.—Cooling Curves of Alloys containing 0.4% Si.

The eutectic point *E*, shown in Figs. 1, 2, and 3, occurs at lower concentrations of carbon as the silicon is increased. It occurs at 4.2 per cent. carbon with 0.4 per cent. silicon; at about 3.8 per cent. carbon with 0.9 per cent. silicon; and at 3.6 per cent. carbon with 1.9 per cent. silicon. Silicon has little effect on the eutectic temperature.

The solidification of the alloys investigated appears to take

place by separation of austenite, or austenite and graphite, from the liquid (except where δ -iron is found), and the diagrams may therefore be regarded as representing the system iron-graphite.

The arrest points below the eutectic line, however, appear

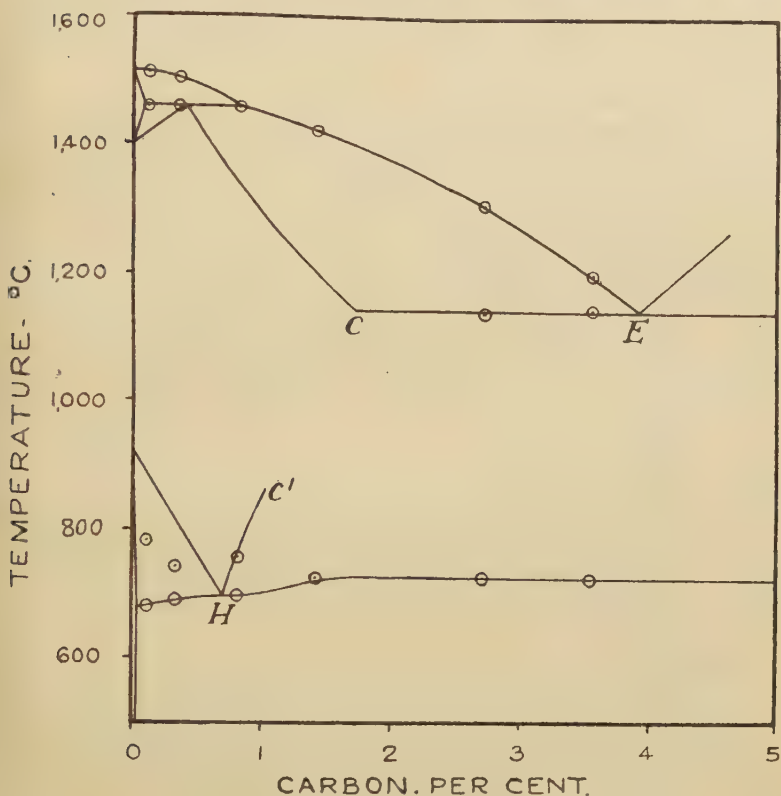


FIG. 2.—Cooling Curves of Alloys containing 0.9% Si.

to correspond to the separation of iron and iron carbide. The microstructures appear to admit of no other conclusion. Specimens SC 2, 3, 4, 5, and 6 contain ferrite and pearlite, and the upper arrest point for each alloy must be due to ferrite formation, and the lower one to pearlite formation. The other alloys all contain a pearlite matrix, free ferrite being absent, as shown in Figs. 17 to 25. In many of these alloys pro-eutectoid cementite

is present, and the arrest points in *SC* 9, 11, and 13 at 754°, 982°, and 989° C. respectively are clearly due to cementite separation. This is illustrated by Fig. 18, in which the cementite needles are clearly seen embedded in a pearlite matrix. In alloys with high

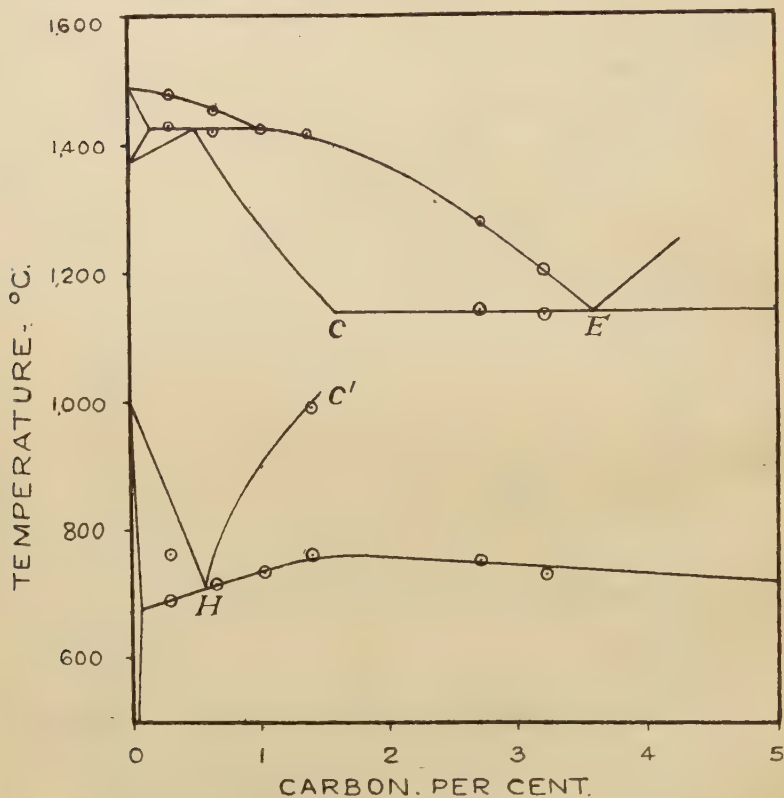


FIG. 3.—Cooling Curves of Alloys containing 1.9% Si.

carbon contents pro-eutectoid cementite is not always clearly visible, and may not be formed.

It will be observed that the eutectoid point in the iron-cementite system occurs at a lower carbon content as the silicon is increased; the eutectoid temperature rises with increase of carbon when the silicon remains constant, and with increase of silicon when the carbon is maintained constant.

It seems clear, then, that the diagrams of Figs. 1, 2, and 3 must be regarded as composite diagrams; that portion down to and including the eutectic represents an iron-graphite system, but at some temperature below the eutectic line the alloys undergo transformations according to the system iron-cementite. For this reason the lower and upper parts of the diagrams have not been joined.

Heat - Treatment Experiments. — The experiments on heat-treated specimens were designed to investigate the region below the eutectic, and to determine, in particular, the reactions between graphite and cementite. The annealing periods used were long and the rates of cooling slow, while the experiments were all carried out *in vacuo* to avoid reactions due to oxygen (or CO and CO₂). The structures observed are therefore considered to represent closely the true equilibrium of the iron-carbon-silicon alloys.

The results are shown in Figs. 4, 5, and 6, in which the alloys examined, and the structures observed, are indicated. The evidence upon which the phase boundaries are fixed is therefore clear.

The three constant-silicon diagrams present broadly the same features, and it will therefore be convenient to consider one in detail and subsequently to point out the small variations in the other two. Fig. 6, representing alloys containing 1.9 per cent. of silicon, has been most fully investigated and may be considered first.

The line *CQ* represents the solubility of graphite in austenite, and is accurately fixed by the experimental data. It represents the temperatures and concentrations at which graphite separates from austenite on cooling. Comparison with Fig. 3 shows that it occurs at a higher temperature than *C'H* representing the separation of cementite, which is formed when the cooling rate is greater. In addition, the times of annealing and cooling in the heat-treatment experiments are such as to ensure a close approach to equilibrium, and it may therefore be assumed that the lines of Fig. 6 are equilibrium lines, and that graphite is the stable form of carbon in the region under consideration. Cementite is then only produced as a metastable phase when the rate of cooling is accelerated. Alloys containing more than 1 per cent. of carbon deposit graphite from austenite on cooling, until the line *PM* is

reached. Figs. 29 and 32 afford evidence of the truth of this statement; they represent alloys *SC7* and *SC10*, quenched from 780°C . (just above *PM*), and consist of graphite and martensite (formed from austenite on quenching). In the 1.9 per cent.

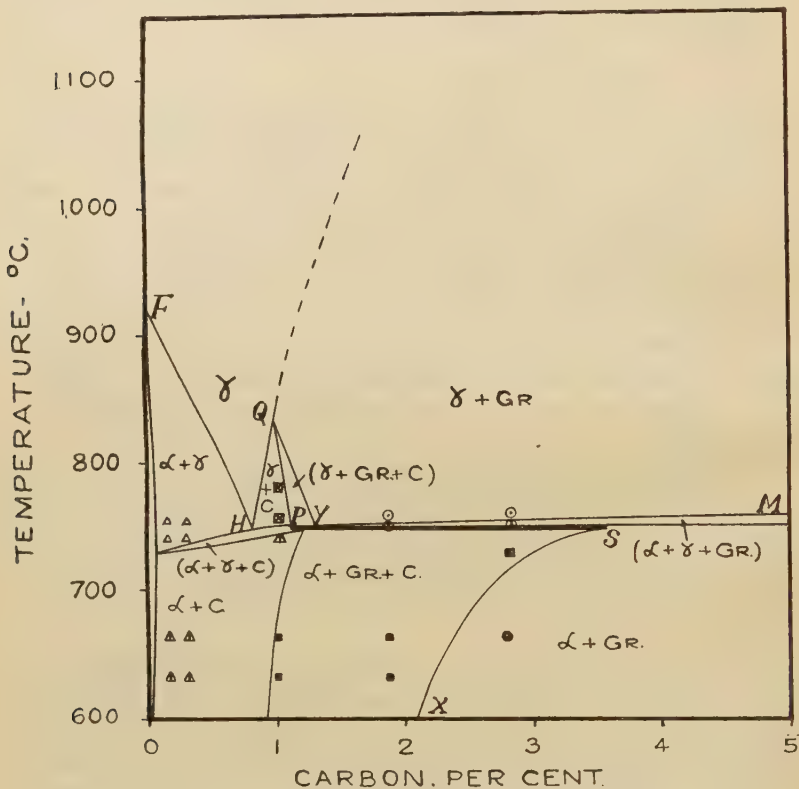


FIG. 4.—Annealed and Quenched Alloys containing 0.4% Si.

silicon alloys of high carbon content, therefore, graphite separates continuously from austenite from the eutectic to the eutectoid temperatures.

On cooling hyper-eutectoid alloys through the line *PM* a further change occurs, and ferrite appears in the specimens, probably accompanied by more graphite; immediately below *PM*, ferrite, graphite, and austenite coexist, as shown in the diagrams, and

illustrated in Fig. 33, which represents the same alloy as is shown in Fig. 32 (SC10) quenched from 765° C.; the structure shows ferrite, graphite, and martensite (austenite). Fig. 37 shows ferrite, graphite, and martensite in SC13. The zone in which

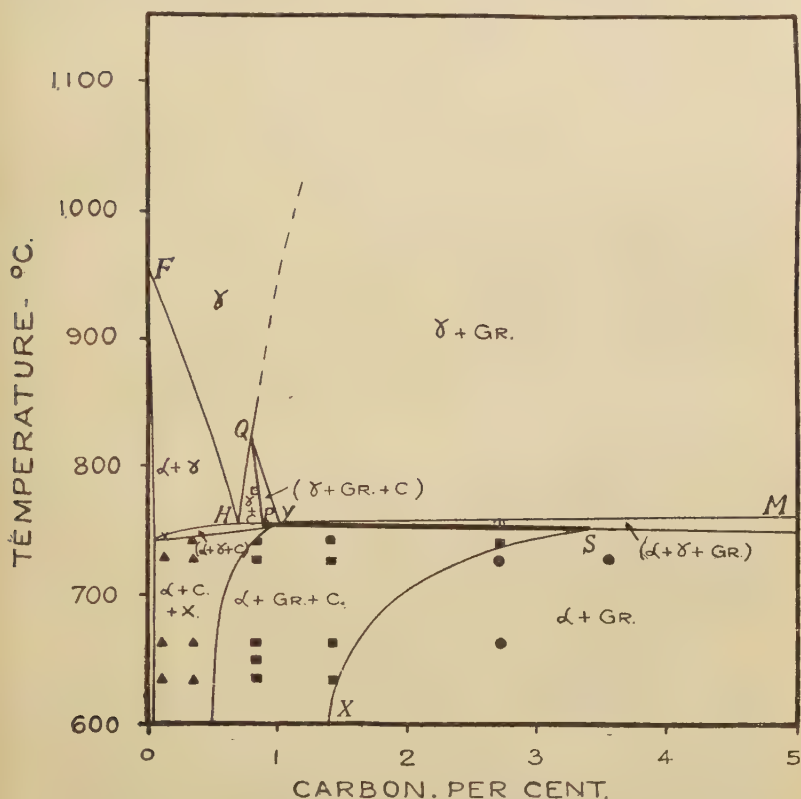


FIG. 5.—Annealed and Quenched Alloys containing 0.9% Si.

these three phases coexist is, however, very narrow, and on further cooling martensite rapidly decomposes. At 750° C. graphite, ferrite, and carbide (pearlite) coexist, as shown in Fig. 34, while Fig. 35 shows the same alloy (SC10) quenched after slowly cooling to 730° C., at which temperature only ferrite and graphite exist.

In hypo-eutectoid alloys ferrite separates from austenite: the line *FH* represents this separation. The exact position of this

line is not fixed by these experiments, but the point *F* is fixed by the work of other investigators, and the general character of the line is doubtless correct. The existence of a ferrite-austenite structure below this line has been confirmed by these experi-

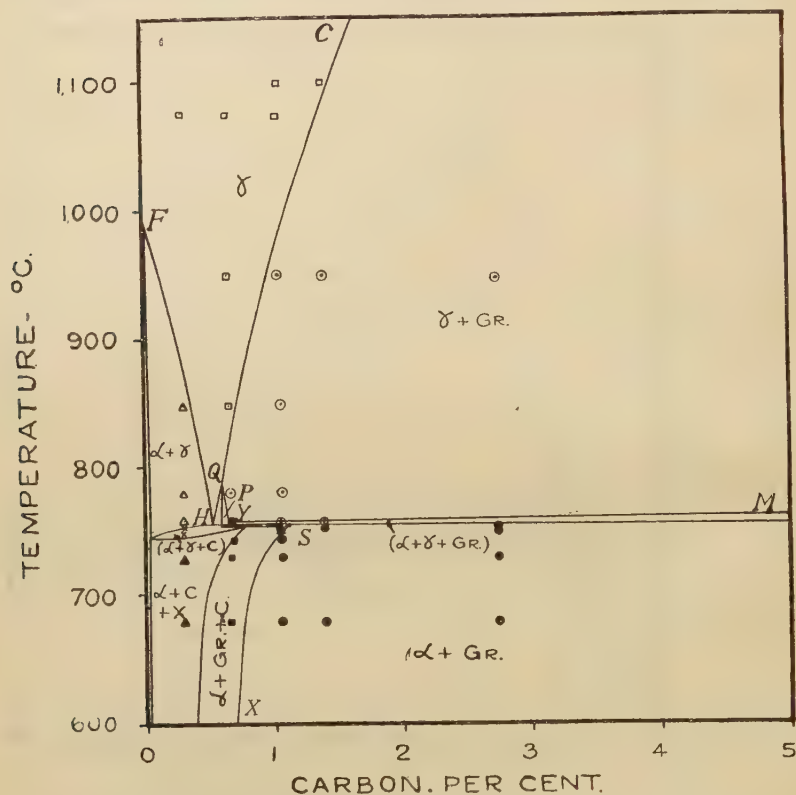


FIG. 6.—Annealed and Quenched Alloys containing 1.9% Si.

ments, and is shown in the diagrams. The iron-carbide eutectoid in these alloys occurs over a range of temperature, as might be anticipated in a ternary system, and as confirmed by experiments on alloy SC4, indicated in the diagram, Fig. 6. Within this eutectoid range ferrite, cementite, and austenite can coexist. Immediately below the eutectoid range the stable phases are ferrite (iron) and cementite: the cementite may, of course, form pearlite with a portion of the ferrite.

It is thus seen that in high-carbon alloys, ferrite and graphite are the stable phases below the critical ranges, and that in low-carbon alloys ferrite and cementite are stable, but between these extremes there is a region, narrow in Fig. 6, in which ferrite, graphite, and cementite all exist together. The existence of such a field is theoretically essential if the relative stabilities of cementite and graphite are as described above, and the experimental confirmation of this field is very satisfactory. It may be illustrated by Fig. 31, showing alloy *SC7* quenched from $752^{\circ}\text{C}.$, at which temperature it consists of ferrite, graphite, and cementite (pearlite).

Figs. 4 and 5, representing alloys containing 0.4 and 0.9 per cent. silicon respectively, possess all the features shown in Fig. 6, and serve to confirm the theory that carbide and graphite can each be stable over certain ranges of composition, and can coexist over an intermediate range. Below the critical range, about $750^{\circ}\text{C}.$, the constitution is of the same type as that of Fig. 6, but above this range an important difference is to be observed, which still further confirms the theory. In Fig. 6 graphite is shown to be the stable form of carbon; but it is clear that if cementite is the stable variety in low-silicon iron-carbon alloys, a zone of composition and temperature must exist in which cementite separates direct from austenite and coexists with it. Evidence of such a zone is given in both Figs. 4 and 5. Alloys *SC8* and *SC9*, containing approximately 1 per cent. of carbon with 0.4 and 0.9 per cent. of silicon respectively, deposit cementite directly from austenite, as shown on the diagrams; but alloy *SC11*, containing 2 per cent. of carbon with 0.4 per cent. of silicon, deposits graphite continuously while cooling through the austenitic range, as do other high-carbon alloys in both series. A zone of stability of carbide in contact with austenite has therefore been established. The case would be still stronger if a zone in which carbide + graphite + austenite could be established. That such a zone must exist cannot be doubted, but the evidence shows that in Figs. 4 and 5 it must be narrow, and must exist in alloys containing a carbon content somewhere between 1 and 1.8 per cent., the exact range not being indicated. Unfortunately, no alloys were available within this range, and its existence could not be verified experimentally. It has, however, been drawn in the diagram as a narrow zone *PQY*.

The point Q , whose existence is demonstrated, but whose position is not accurately fixed, marks the place on the carbon solubility curve above which carbon separates from solution as graphite, and below which it separates as cementite. It is, theoretically, a very important point, for if the conception of separate iron-graphite and iron-cementite systems be accepted, it marks the point of their intersection. Its existence, which the author considers to be proved by the facts now advanced, will be used to develop and test a new theory of ternary iron-carbon-silicon alloys, and to account for the constitution of the cast irons. The theory is applicable also to other ternary iron-carbon alloys containing graphite.

Below the eutectoid temperature within the field called ferrite + carbide certain unusual structures were observed, which require further investigation. In some alloys, indicated in the tables of the Appendix, another constituent was observed, which has been called "X." The characteristic appearance is shown in Figs. 27 and 28, representing SC_4 and SC_6 quenched from 730° and 738° C. respectively. In samples etched with 1 per cent. nitric acid in alcohol the constituent is indistinguishable from the carbide, except that it contains a large number of fine specks, which appear in unetched specimens and are probably graphite. In some cases, as in SC_6 , they exist outside the boundaries of the constituent, in the surrounding ferrite, as if decomposition into ferrite and graphite had taken place on the outside of the particle. They are found in low-carbon irons containing 1 per cent. or more of silicon. They have not been further investigated, but they are clearly of importance.

The constituent X differs from carbide, in that it can be seen in unetched specimens (see Fig. 28), and is also attacked in a different manner by sodium picrate, which blackens Fe_3C , but only stains the new constituent slightly (generally patchily).

The existence of this new constituent does not affect the author's theory of carbon-graphite equilibrium.

THE EQUILIBRIUM BETWEEN IRON AND CARBON.

Numerous attempts have been made to represent graphically the equilibrium between iron and carbon, and to take account of

the fact that carbon can exist in iron alloys in two forms, iron carbide and graphite. Although conclusive evidence is lacking, the possibility of the existence of graphite as a stable phase in pure iron-carbon alloys has been advanced by several workers, and a certain amount of evidence that this may occur in high-carbon alloys has been advanced. It is well established that in certain ternary alloys, particularly those containing silicon, graphite can exist as a stable phase over a wide range of temperature and composition, and this has led to the suggestion that the iron carbide phase is not necessarily stable even in pure iron-carbon alloys. Its occurrence over wide ranges of composition and its persistence under various forms of heat treatment, both in pure iron-carbon alloys and in cast irons, has led to the introduction of a number of equilibrium diagrams to account for the varying behaviour of these materials.

The most generally accepted diagrams are those consisting of a double equilibrium diagram, in which the systems iron-carbide and iron-graphite are both represented. Certain investigators, notably Roozeboom and Benedicks, have suggested diagrams in which graphite is represented as a stable phase, and the lines referring to the graphite equilibrium are drawn at higher temperatures throughout than those representing the carbide equilibrium. On the other hand, Rosenhain has suggested a diagram in which carbide is represented as a stable phase and graphite as the unstable modification. None of these diagrams is complete in the sense required by the phase rule, and they are all alike in one respect, that only one form of carbon is represented as stable over all ranges of temperatures.

The two types of diagrams, drawn to be consistent with the phase rule and differing but little from those suggested by other investigators, are shown in Figs. 7 and 8. In Fig. 7 graphite is shown as the stable phase, and the graphite system is represented by dotted lines where it does not coincide with the carbide system. Fig. 8 represents the corresponding diagram in which the carbide system, represented by full lines, is stable. In Fig. 7 the graphite diagram is stable over all ranges and temperatures, and in Fig. 8 the carbide diagram is always the stable type.

Neither of these diagrams offers a satisfactory explanation of the phenomena connected with the behaviour of iron-carbon

alloys, whether these be steels or cast irons. As a result of investigations described in this paper into the equilibrium of the ternary system iron-carbon-silicon, the author has been led to an examination of the consequences that would follow if the two

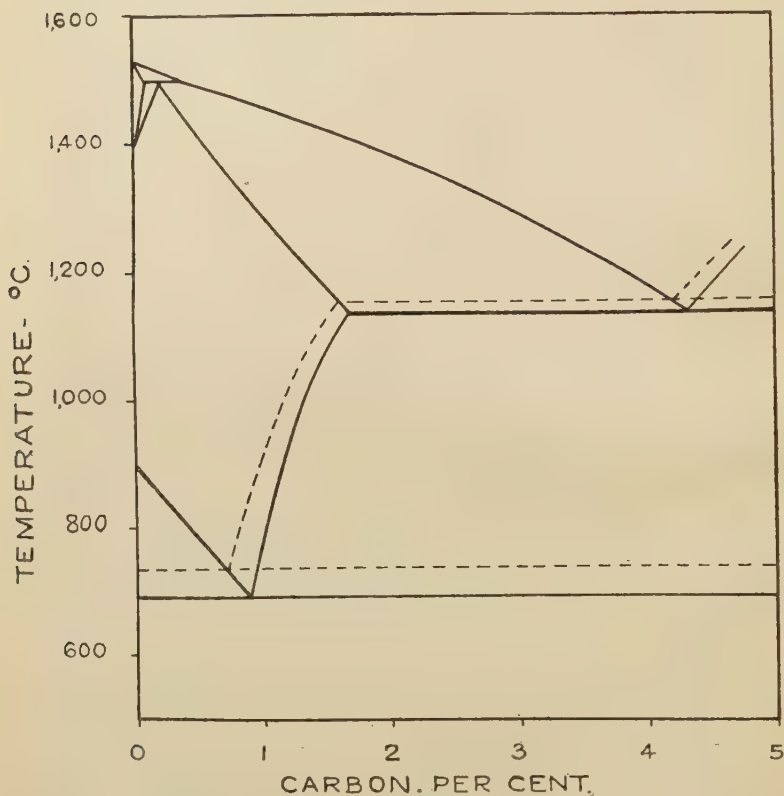


FIG. 7.

diagrams representing graphite and carbide respectively overlapped, instead of remaining always one above the other—that is, if at some temperature the system changed from one in which graphite is stable to one in which carbide is stable. Such a possibility is by no means inconceivable, and might, in a binary system, occur as a result of the alteration in one of the degrees of freedom (although there is no experimental evidence that such

occurs), and in a ternary system such a change might well be induced by the presence of a third element. In this latter case, the diagrams representing the system would require modification in a manner that will be considered later, and it will be convenient

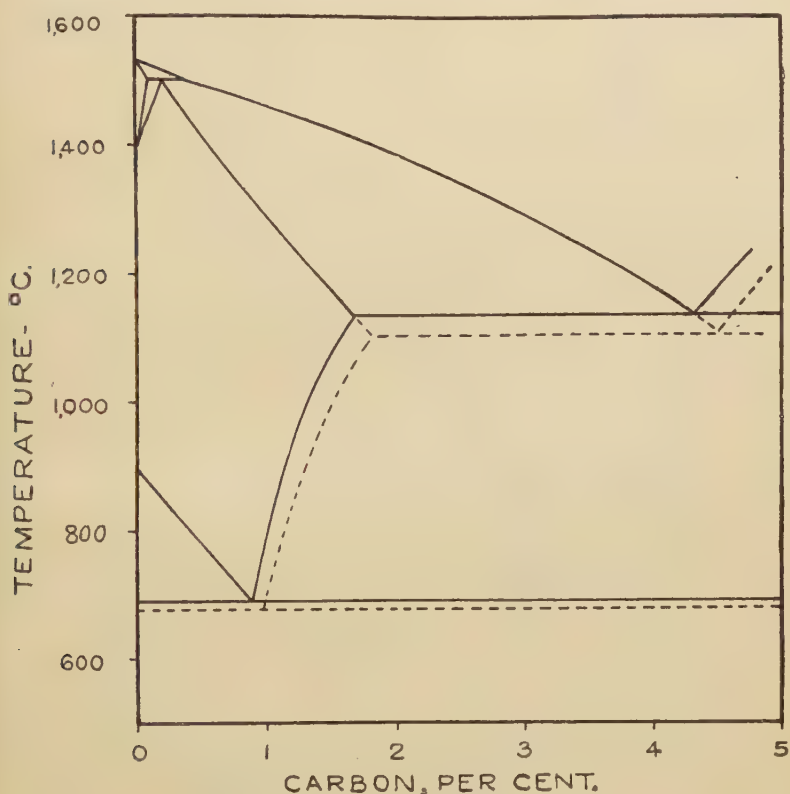


FIG. 8.

to approach the question by assuming the possibility of such a change in a simple binary system.

Consider first of all the double diagram in which carbide is represented as the stable phase at high temperatures, but in which the graphite system becomes stable at lower temperatures, between the eutectic and eutectoid temperatures. Such a case may be represented as in Fig. 9, in which the two diagrams are shown,

but in which the graphite system crosses the carbide system at the temperature of the point Q . If now the stable reaction lines be picked out from this double diagram, and the necessary simple modifications necessary to preserve it as a phase diagram be made;

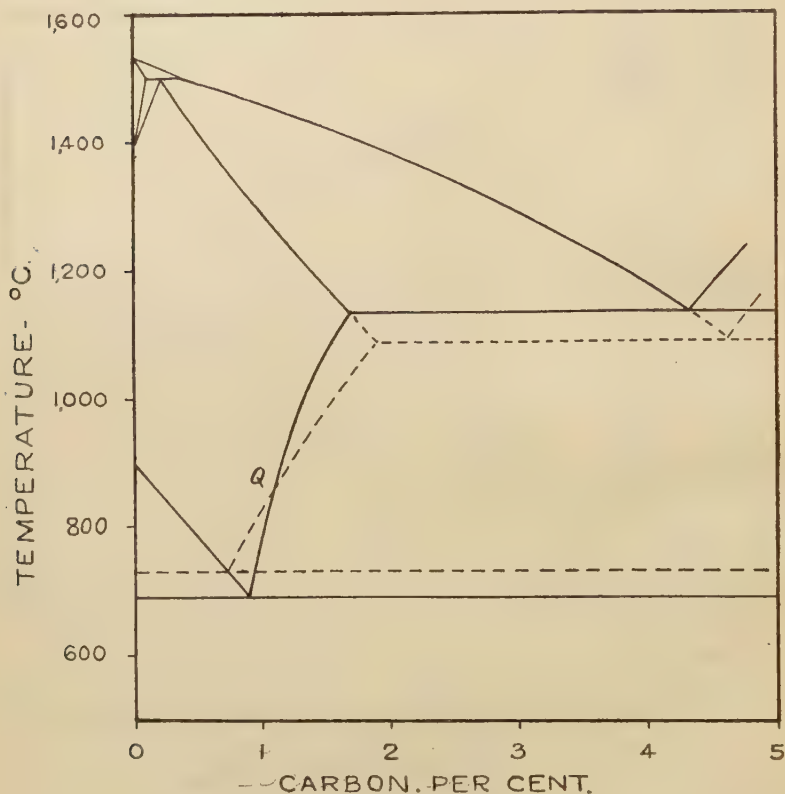


FIG. 9.

the form shown in Fig. 10 is arrived at, in which the stable constituents in the various phase fields are indicated. This diagram differs from the ordinary iron-carbon equilibrium diagram in that graphite becomes the stable phase at the temperature Q , and the eutectoid, which now occurs at a rather higher temperature, consists of α -iron and graphite. The stable phases at temperatures below the eutectoid are everywhere α and graphite.

A similar method of attack in the case in which graphite is stable at the high temperature and carbide at lower temperatures is represented in Figs. 11 and 12, Fig. 11 representing the two diagrams superimposed on one another and crossing also at the

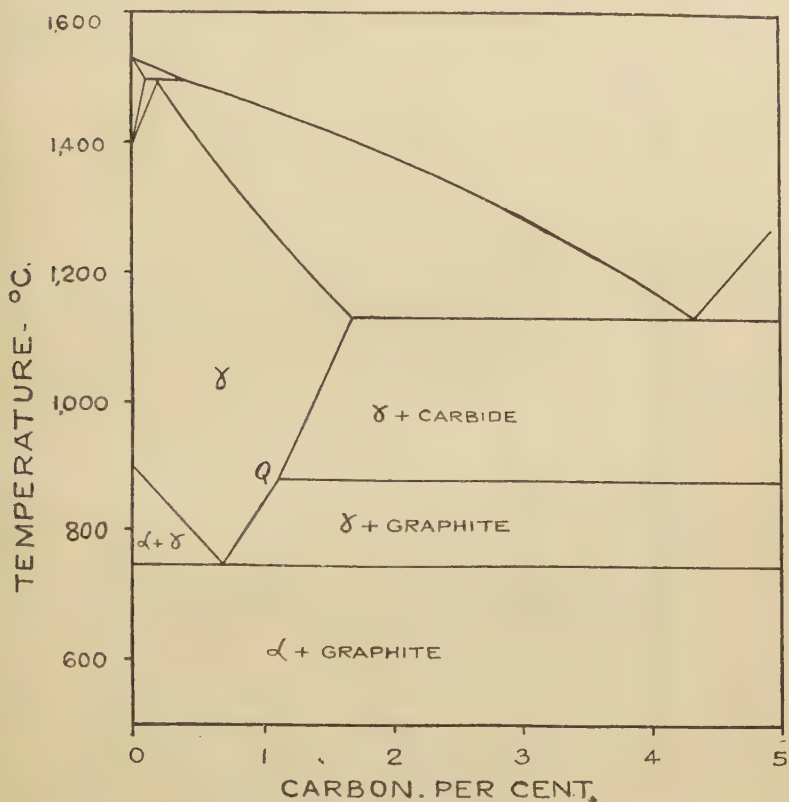


FIG. 10.

point Q , and Fig. 12 representing the stable binary diagram deduced from these two forms.

It must be emphasised that these are hypothetical cases for which there is no evidence in the pure binary iron-carbon system, for there is nothing to suggest that any probable modification in the degrees of freedom of the system would produce such a result. On the other hand, a modification of this kind is not only

conceivable, but, as will be shown, is highly probable when another element is added to the system, but the diagrams representing such a case will require modification in order to make them consistent with the known laws of ternary equilibria. This modifica-

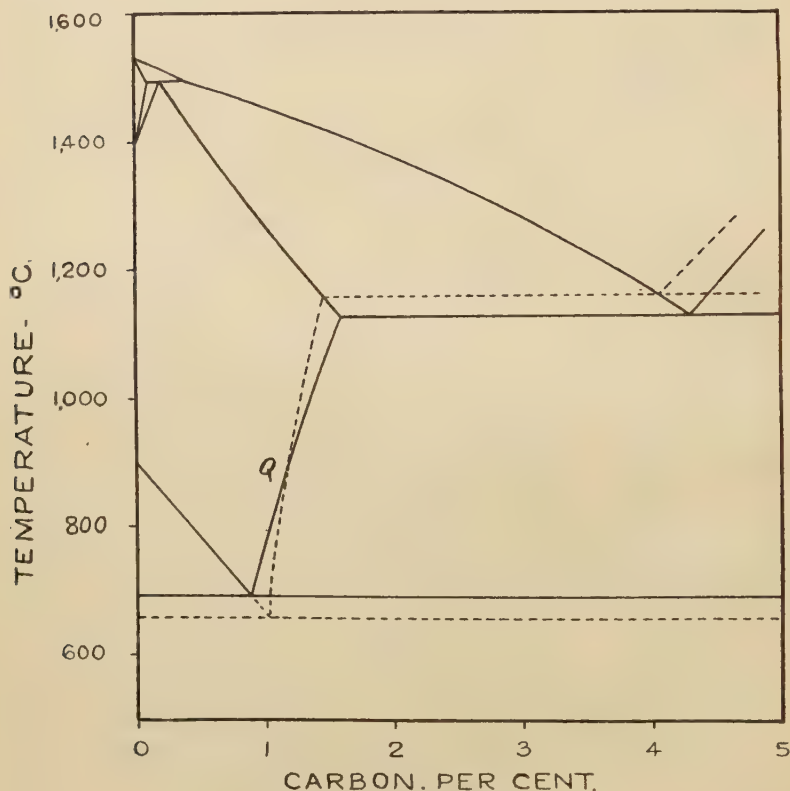


FIG. 11.

tion is quite simple in principle, although it may lead to much more complicated forms of diagram. When the third element is present, the horizontal lines in the binary system, representing the boundaries between phase fields containing two constituents, must be replaced by zones of a definite width, and the transformation represented by those zones will not in general, in the ternary system, occur at fixed temperatures. The temperature range will

vary with the composition of the alloy ; in other words, the lines bounding these zones need not be horizontal on the diagram.

Such modification might take the simple forms shown in Fig. 13, in which the diagram would be relatively little altered ;

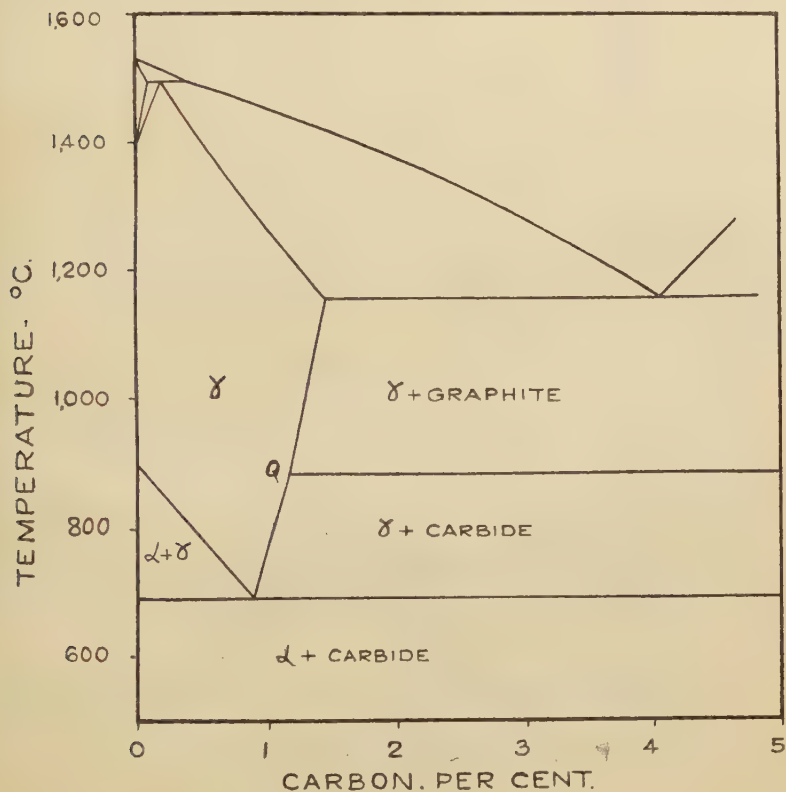


FIG. 12.

but, in general, the zones starting from the points *E*, *Q*, and *R* will meet one another, at a point which will depend on the manner in which the third element modifies the system, and it will be interesting to examine the consequences which will follow in such cases. Dealing first of all with the modifications of Fig. 12, two probable modifications at once suggest themselves, one corresponding to the case in which the field starting from the

point Q falls and meets the field representing the eutectoid, starting from the point R . The type of diagram produced in this case is shown in Fig. 14, which then becomes, of course, a section

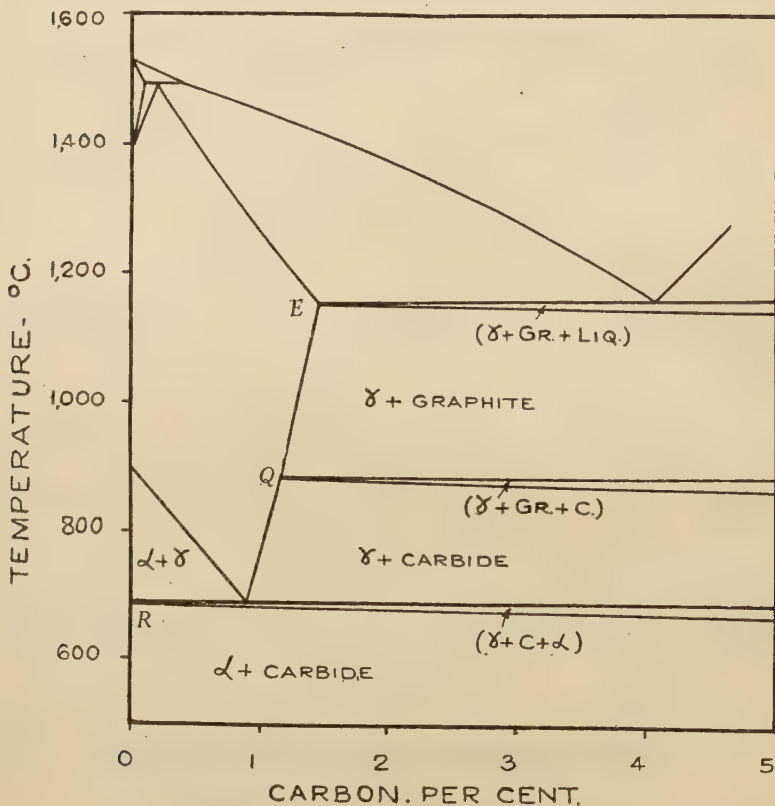


FIG. 13.

through a ternary model representing the system iron-carbon-Y, where Y is the third element.¹ In Fig. 14 it will be observed that a new phase field is introduced, additional to the narrow zones

¹ It is further necessary to assume that the addition of Y introduces no new phases. This assumption is justified in most iron-carbon systems for small additions of an added element. New phases are not introduced when the added element dissolves in the iron or forms carbide isomorphous with iron carbide. When a new phase is introduced the theory will require modification within the range of existence of that phase.

resulting from the widening of the horizontal lines of the binary diagram. This new field, N_1NVV_1 , represents a region of composition in which the three phases α -iron, carbide, and graphite

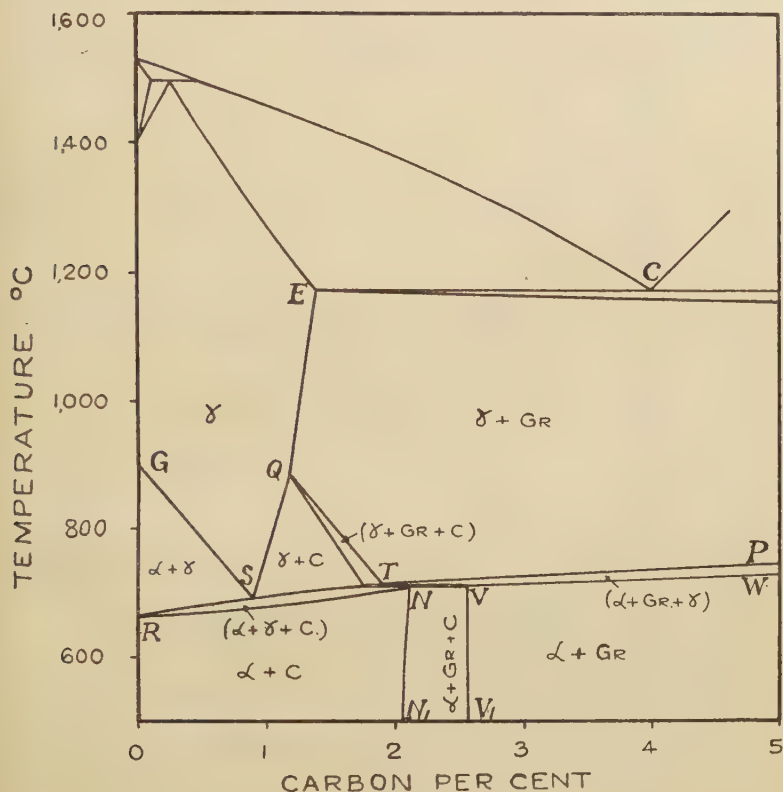


FIG. 14.

can coexist, such a phase field being clearly possible in a ternary system, although inadmissible in a binary system.

The second case, in which the field starting from the point Q rises and meets the binary eutectic zone starting from the point E , is represented in Fig. 15; in general type it is somewhat similar to Fig. 14, and two new ternary fields $TWXV$ and N_1NVV_1 should be noted, the first representing the coexistence of γ -iron, carbide, and graphite, and the second the coexistence of α ,

carbide, and graphite. In both Figs. 14 and 15 it will be observed that a region representing α + carbide occurs at low carbon concentrations and is succeeded by a field representing α + carbide + graphite. In Fig. 14 this second field is succeeded by a third,

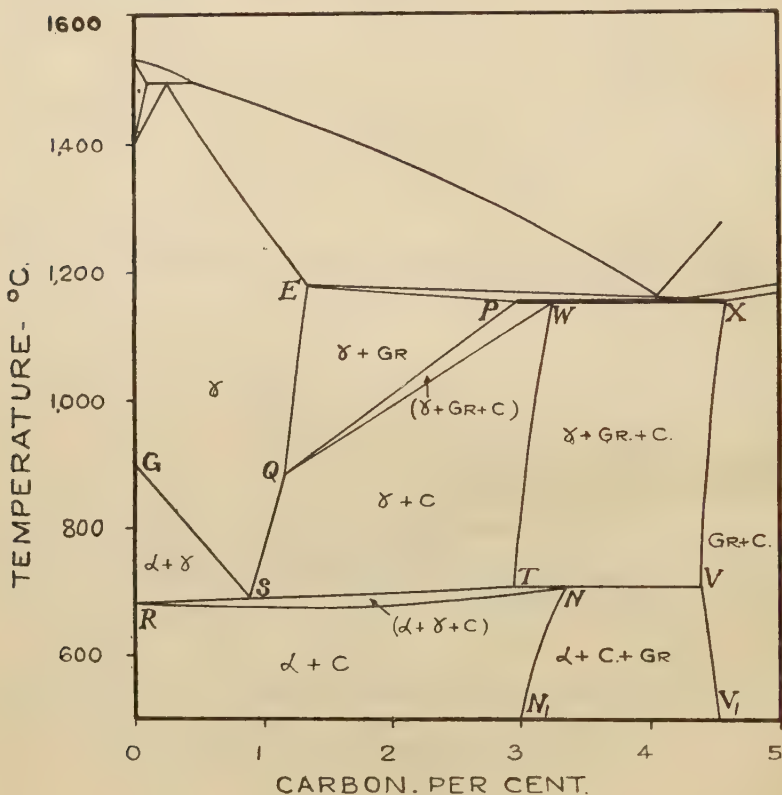


FIG. 15.

at a higher carbon concentration, in which α + graphite coexist, while in Fig. 15 these two fields are succeeded by one in which carbide + graphite coexist.

An exactly similar pair of diagrams can be developed in the same way from Fig. 10, but they will differ from Figs. 14 and 15 simply in that graphite must be substituted for carbide and carbide for graphite, so that below the eutectoid region alloys

corresponding to these systems would consist of α + graphite in the region of lowest carbon content, α + carbide + graphite in the intermediate zone and α + carbide or carbide + graphite in regions of high carbon content. Thus, from the simple assumption that the carbide and graphite systems intersect in a three-component system, four types of diagram representing theoretical relationships between the different phases may be developed, and each of these four theoretically possible diagrams differs in some notable respect from all the others.

The above cases do not exhaust the possibilities, since slightly different diagrams would be given if the eutectic zone were raised or the eutectoid zone depressed by an increase of carbon. The modifications in such cases would be slight, and would not affect the argument developed above.

EXPERIMENTAL VERIFICATION OF THE THEORY.

The above theory may now be examined in the light of the experimental evidence. In the first place, the theory is based on the fundamental assumption that the iron-carbide and iron-graphite systems intersect at a point on that boundary of the austenite field representing carbon solubility. *Ample experimental evidence has already been advanced for that assumption* (p. 144). By the simple application of the known laws of equilibrium in ternary systems, the consequences of that assumption have been analysed, and five possible forms of equilibrium diagrams have been deduced representing the constitution of the ternary alloys, namely, Figs. 13, 14, and 15, and two others, not reproduced, similar to Figs. 14 and 15, except that carbide must be written for graphite and *vice versa*. But if the theory is correct, the experimental diagrams should possess the form of one of these theoretical possibilities, all of which possess their own peculiarities, and are readily distinguishable. *A comparison shows that the experimental results can be represented completely by a diagram in the form of Fig. 14 and by none of the others.* Figs. 5 and 6 contain all the phase fields of Fig. 14, and no others. Fig. 4 is of the same type, but in this instance the two fields representing (γ + C + graphite) and (γ + C) have been inserted, without experimental

evidence, since alloys suitable for verifying their existence were not available.

The experimental results, therefore, constitute very strong support for the theory.

APPLICATION OF THE THEORY TO THE CAST IRONS.

The present paper would be incomplete without some account of the manner in which the properties of the iron-carbon alloys, especially the cast irons, can be explained by the author's theory.

It can clearly not yet be applied in detail to account for all the phenomena of complex cast irons, containing elements whose influence has not yet been investigated (manganese, sulphur, phosphorus, &c.), to which reference will be made below ; but it can be used to account for the general behaviour of most cast irons, in which the influence of silicon and carbon are predominant. In the following analysis such irons only are considered.

In the first place, the theory accounts for the existence of graphite as a stable form of carbon in high-carbon alloys (cast irons), whereas cementite alone is found in low-carbon alloys (steels). In most of the ordinary cast irons of commerce experiments have clearly demonstrated that graphite is the stable form of carbon. The diagrams (Figs. 4, 5, and 6) clearly account for this fact, for they indicate graphite as the stable form in all alloys containing more than 2 per cent. of carbon and 0.4 per cent. of silicon, with the exception of a short range of temperature, in the region of 700° C., in which some carbide can exist when the silicon content is low. The ordinary cast irons practically all fall within the range of composition in which graphite only is the stable form of carbon. It is only in certain kinds of malleable iron, to which reference will be made below, that carbide can exist as a stable phase.

The proved stability of graphite in cast irons has frequently been regarded as evidence that iron carbide is everywhere unstable ; this view is still widely held, although experimental data in its favour are scanty and not very convincing. Indeed, the weight of evidence seems to be against this view, for not only is iron carbide extremely stable under heat in the steels, but it may be synthesised readily in a variety of carburising media at tem-

peratures at which it is held to be unstable. The author's theory is consistent with the stability of iron carbide in the range of the ordinary steels, and his equilibrium diagrams in this range of composition require no modification in principle from those normally accepted and used. The intermediate types of alloy, in which both forms of carbon are stable, are scarcely represented in commercial alloys, as they fall in the zone of little usefulness between the steels and cast irons. Many of the author's alloys, however, fall within this region, and the study of their constitution has made it possible to bridge the gap between the steels and cast irons and arrive at a proper understanding of their true relationship.

There is thus presented for the first time a theory which accounts, qualitatively, for the existence of graphite as the stable form in cast irons, and iron carbide in steels, the case being completed by the demonstration of an intermediate zone of alloys in which both forms can exist together.

It must be noted that the possible existence of graphite as a stable phase in pure *high* carbon-iron alloys is not excluded. There is a certain amount of evidence that it can occur; the author's experiments have not extended to this region. Its existence would not affect the present work nor the conclusions drawn from it.

The author's theory may be regarded as superseding the double diagram for iron-carbon alloys, for it represents the facts relating to equilibrium conditions by means of ternary equilibrium diagrams: they are really sections through the ternary equilibrium model. But commercial irons are not usually in a condition of complete equilibrium, and a double diagram may well be utilised to account for a departure from equilibrium. Such a diagram can be logically developed from the equilibrium sections by producing the line *HQ* (Figs. 4, 5, and 6), representing the solubility of carbide in austenite, until it meets the austenite solidus line. From this latter intersection a metastable austenite-carbide eutectic zone commences, extending to regions of higher carbon content. Fig. 16 represents this diagrammatically (since the author has no reliable quantitative data), the dotted portion representing the metastable diagram. The iron-carbide eutectoid may be similarly extended to complete the metastable diagram,

but it is not shown in Fig. 16 on account of the complicated character of this lower region. A diagram, partly stable and partly metastable, representing the relations between iron and iron carbide in these ternary alloys may thus be realised, and if graphite formation can be prevented, this diagram should represent, qualitatively at any rate, the behaviour of the alloys. That it does do so is evident, for it is known that by suitable chilling graphite formation is prevented, and structures (white iron) entirely consistent with the carbide diagram are produced.

Between these two extremes, white iron and completely graphitised iron, there can be a variety of structures, and the commercial irons are usually of an intermediate character. When the silicon content is fairly high, as in most cast irons, graphite forms readily at high temperatures according to the stable system ; but there is ample evidence that graphite formation is sluggish at lower temperatures, and quite slow rates of cooling are necessary for its complete formation. With ordinary cooling rates a temperature is normally reached at which the rate of graphite formation cannot keep pace with the fall in temperature, and carbide may then be formed according to the metastable diagram. With ordinary grey irons this point is not arrived at until the eutectoid range is reached. In this range of temperature the residual austenite decomposes, which may happen according to the metastable or stable systems, producing respectively pearlite or ferrite and graphite ; or it may happen by a combination of both. Now, a glance at the equilibrium diagrams, Figs. 4, 5, and 6, shows that in the sections of low silicon content the carbide suddenly becomes relatively more stable, as indicated by the much wider range of composition over which it exists ; it would therefore be anticipated that the tendency to follow the metastable system would suddenly increase, particularly as graphite formation is quite sluggish in this region. This, indeed, is in accord with experience, for it is characteristic of cast irons, over a fairly wide range of composition, that they deposit graphite during the eutectic and post-eutectic intervals, but become pearlitic in the eutectoid zone. The author's theory appears to offer a satisfactory explanation of this behaviour. In high-silicon irons the relative stability of carbide immediately below the eutectoid is much less ; it is much less in the 1.9 per cent. section than in

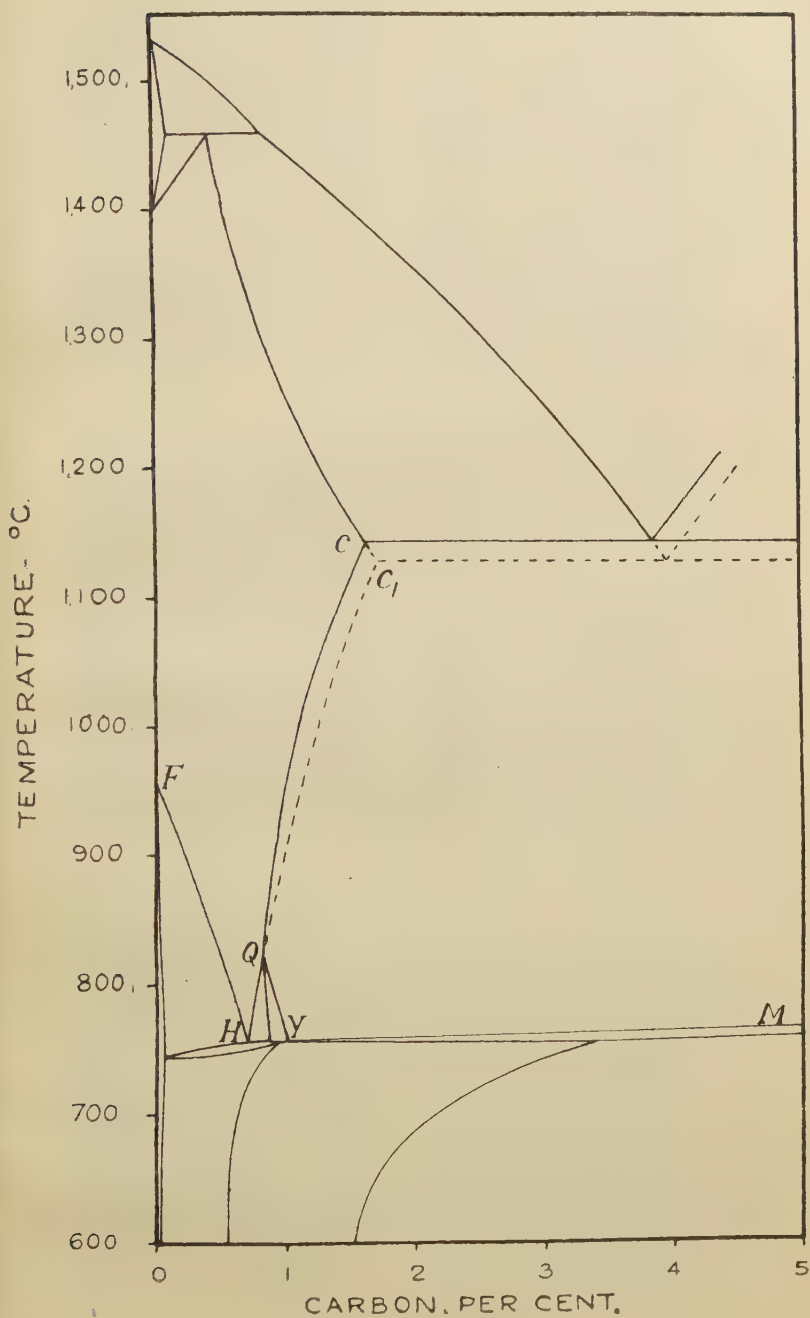


FIG. 16.

the 0.9 per cent. section, and appears to be decreasing very rapidly with the increase of silicon content. It is therefore easy to account for the separation of free ferrite in high-silicon irons, which occurs according to the normal eutectoid of the graphite system, and increases in amount as the silicon rises and the rate of cooling falls.

The theory will well account for some of the phenomena of graphitisation in white irons. These irons, produced as described above, according to the metastable system by the rapid cooling of low-silicon irons, deposit graphite when reheated and cooled slowly. During the first stage of graphitisation, graphite separates from austenite, according to the stable diagram, and possibly also by direct decomposition of carbide, until immediately above the critical range austenite and graphite are the only phases present. But it is known that to secure complete graphitisation cooling must be slow, and must continue to well below the critical range (about $750^{\circ}\text{C}.$). In Blackheart practice it is considered essential to cool *very slowly* from 750° to $650^{\circ}\text{C}.$, to complete the graphite formation. Slow cooling favours the separation of graphite, but graphitisation can never be complete until the critical range is passed, for immediately above this temperature the austenite has the eutectoid composition. Now, according to the older double diagram theory, graphitisation should become complete upon annealing just below the critical range, say $740^{\circ}\text{C}.$, but, in fact, it is known that this does not happen, and that a temperature range of further graphitisation occurs below the eutectoid. This is explained by the new theory, for there are shown to exist within the range of white iron compositions, alloys in which carbide is stable with ferrite and graphite below the eutectoid; the shape of the diagram (the line SX) indicates, however, that this carbide is rapidly dissociated as the temperature is further reduced, and at $650^{\circ}\text{C}.$ all irons in the commercial malleable range consist of ferrite and graphite only, when in equilibrium.¹

The influence of other elements has naturally not been considered, since no experimental evidence bearing on this aspect of cast irons has been obtained. Nevertheless, the theory appears

¹ The above only applies to graphitisation phenomena in which oxidising agents play no appreciable part. The equilibrium between iron and carbon is known to be greatly affected in the presence of oxygen (CO and CO_2) and requires separate consideration.

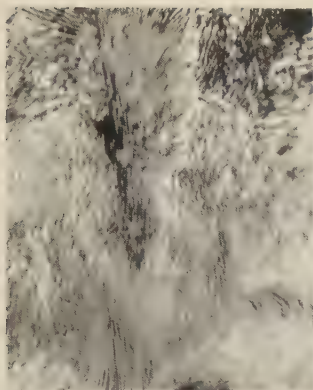


FIG. 17.—SC8. Cooling curve ingot. $\times 1250$.



FIG. 18.—SC11. Cooling curve ingot. $\times 1250$.



FIG. 19.—SC12. Cooling curve ingot. $\times 1250$.

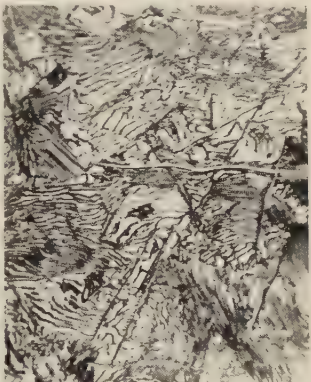


FIG. 20.—SC12. Cooling curve ingot. $\times 1250$.

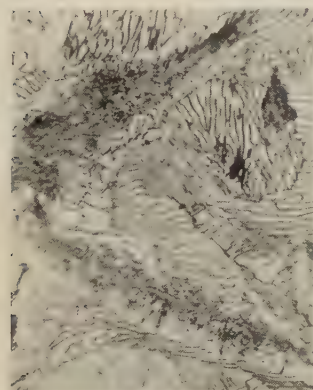


FIG. 21.—SC13. Cooling curve ingot. $\times 1250$.

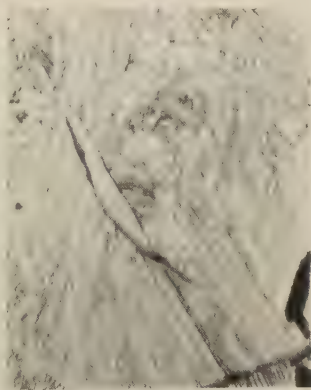


FIG. 22.—SC14. Cooling curve ingot. $\times 1250$.

(Reduced in reproduction to four-fifths.)

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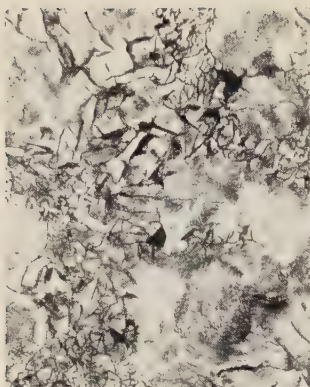


FIG. 23.—SC16. Cooling curve ingot. $\times 150$.



FIG. 24.—SC18. Cooling curve ingot. $\times 1250$.

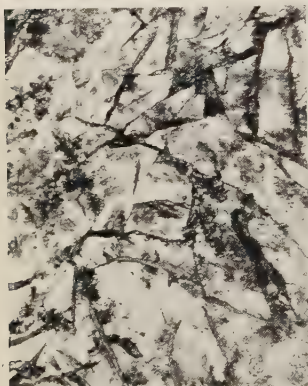


FIG. 25.—SC19. Cooling curve ingot. Etched. $\times 150$.



FIG. 26.—SC19. Original ingot, as polished. $\times 150$.



FIG. 27.—SC4. Quenched from 730°C . Etched. Showing constituent X. $\times 1400$.

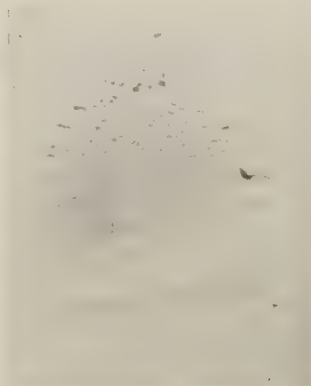


FIG. 28.—SC6. Quenched from 738°C . Unetched. Showing constituent X. $\times 1400$.

(Reduced in reproduction to four-fifths.)

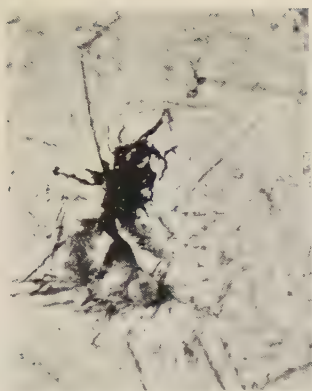


FIG. 29.—SC7. Quenched from 780° C. Etched. γ (martensite) + graphite. $\times 300$.



FIG. 30.—SC7. Quenched from 765° C. Etched. γ (martensite) + graphite + pearlite. $\times 300$.



FIG. 31.—SC7. Quenched from 752° C. Etched. Graphite + ferrite + carbide (pearlite). $\times 150$.

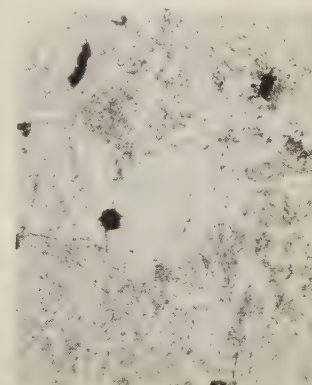


FIG. 32.—SC10. Quenched from 780° C. Etched. Graphite + γ (martensite). $\times 150$.



FIG. 33.—SC10. Quenched from 765° C. Etched. Graphite + ferrite + γ (martensite). $\times 300$.

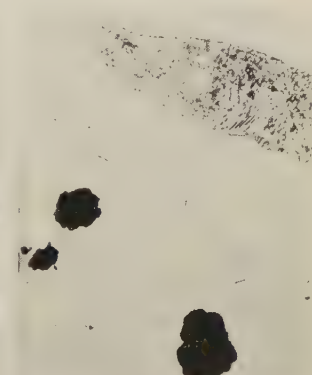


FIG. 34.—SC10. Quenched from 750° C. Etched. Graphite + ferrite + carbide (pearlite). $\times 150$.

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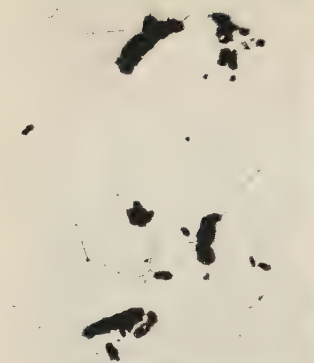


FIG. 35.—SC10. Quenched from 730° C. (centre of specimen). Etched. Graphite+ferrite. $\times 150$.

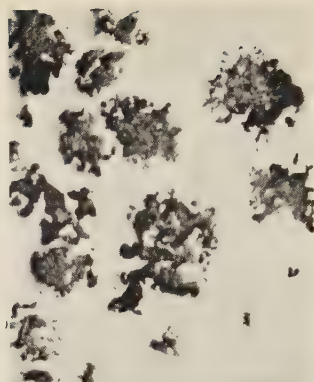


FIG. 36.—SC10. Quenched from 730° C. (surface of specimen). Etched. Graphite+ferrite. $\times 150$.

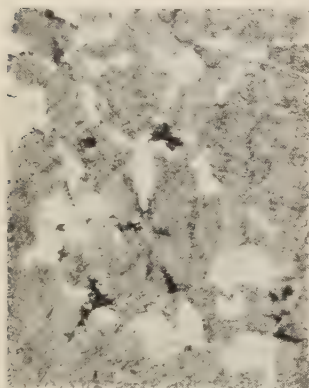


FIG. 37.—SC13. Quenched from 765° C. Etched. Graphite+ferrite+ γ (martensite). $\times 150$.

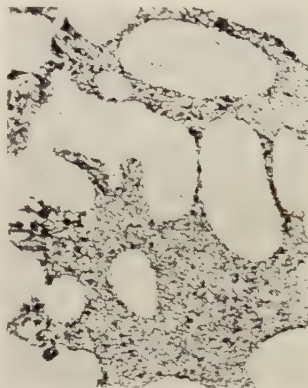


FIG. 38.—SC16. Quenched from 765° C. Etched. Graphite+ferrite. $\times 150$.

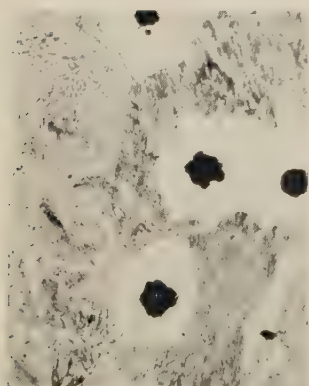


FIG. 39.—SC8. Quenched from 663° C. Etched. Graphite+ferrite+carbide (pearlite). $\times 150$.

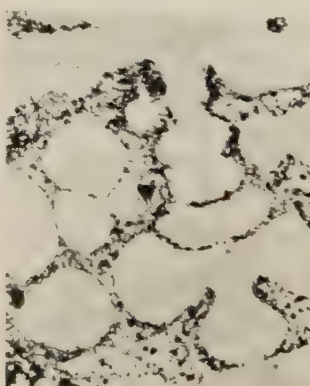


FIG. 40.—SC14. Quenched from 663° C. Etched. Graphite+ferrite. $\times 150$.

(Reduced in reproduction to four-fifths.)

to be capable of extension in a simple manner to take account of such influence, provided that new phases are not introduced into the more complex alloys. It is known that certain elements, as, for example, manganese and chromium, tend to increase the amount or stability of carbide, while others, such as nickel and aluminium, promote graphite formation. The addition of another element to such a system would be expected to alter the transformation temperatures. In the present case, a very small alteration in the relative positions of the carbide and graphite solubility lines would have a relatively large effect on the position of their intersection, that is, the point Q , and consequently on the carbide-graphite equilibrium, for it is mainly on the position of Q that the stabilities of these two phases depend.

An element which moves the point Q to the right (that is, in the direction of higher carbon contents) will increase the range of stability of carbide, both above and below the critical range. In cast irons, the effect below the critical range should be more noticeable than that above the critical range—that is, pearlite carbide should become stable more rapidly than pro-eutectic carbide, since the range of carbide stability is greater below than above the critical range. This is, of course, in general accord with the behaviour of commercial irons, in which pearlite is commonly found, whereas pro-eutectic cementite is of rare occurrence. But stronger evidence is to be found in some recent work by Kikuta¹; in studying the effect of manganese and sulphur on the graphitisation of a malleable iron containing 2.6 per cent. of carbon and 1.15 per cent. of silicon, he investigated the effects of each element on both stages of graphitisation. In the case of manganese, he found that the effect of increasing this element had an immediate profound effect on the second stage of graphitisation below the critical range (his annealing temperature was 710° C.); with 1.02 per cent. of manganese the rate was very slow, and with 1.26 per cent. the second stage was entirely prevented. Up to this concentration, the effect on the first stage was not very great (the graphitisation time at 925° C. rose from five hours to eight hours), but with further increases in manganese the rate of the first stage became markedly slower, and when 3.16 per cent. of

¹ Kikuta, "Malleable Cast Iron and the Mechanism of its Graphitisation," *Science Reports of the Tôhoku Imperial University*, 1926, vol. xv. p. 115.

manganese was present, no graphitisation at 925°C . was observed. The iron remained white. Similarly, 0.072 per cent. of sulphur entirely prevented graphite formation below the critical range, without affecting the rate of formation above this range, but a further addition, to 0.2 per cent., markedly increased the stability of carbide at higher temperatures, although, in this instance, enough sulphur was not added to render pro-eutectoid graphite unstable.

The above tests become immediately intelligible on the author's theory, but cannot be explained by the older double diagram theory.

There is another fact which must be accounted for by any theory of cast iron. It is well known, though not always sufficiently recognised, that the character of cast iron depends on the amount of carbon present quite as much as on the amount of silicon, and that high carbon promotes graphite formation, just as does high silicon. Carbon and silicon may be regarded as replaceable in this respect, though not necessarily in equal amounts. White iron can be made with high carbon if the silicon be low, and with high silicon, if the carbon be low (the latter is more correctly a steel). Similarly, graphite can be the stable form with low-silicon iron, provided the carbon is high, and in low-carbon alloys, if the silicon be increased.

The essential differences between the Whiteheart and Blackheart malleable processes now become more intelligible. The European process favours carbide stability below the eutectoid, since the malleabilising consists in carbon elimination; the American process retains the carbon in the iron, and throws the equilibrium into the region of graphite stability. The difference in the sulphur content, of course, is also a vital factor, acting in the same direction, in the manner explained above.

These facts find recognition in the author's theory of ternary equilibrium, in which the carbon condition is determined by the composition of the alloy; either form may be stable, or both may exist together, and variations in carbon concentration may alter the equilibrium as well as variations in silicon. A glance at any of the diagrams of Figs. 4, 5, or 6, shows that as the carbon increases in concentration, even though the silicon remains constant, so does the stability of graphite increase, until it becomes the only stable form of carbon. The double diagram theory fails

to express the above facts, since it shows only one form of carbon as stable.

The author's theory is more likely to find immediate application to malleable iron problems than to grey iron problems, partly because the former iron is used in a condition closely approaching, if not actually attaining, structural equilibrium, and partly because it is generally a purer material than the latter. Grey iron is usually in a metastable condition, since it is cooled too rapidly for equilibrium to be attained between the various constituents. Nevertheless, it should be possible to treat it in a manner similar to that described in this paper, for it should be quite possible to construct constitutional diagrams for different rates of cooling. The positions of the critical points in all iron-carbon alloys vary according to the cooling rates; this is well known in the steels; and it is also known that graphite formation can be readily suppressed—more readily than carbide formation. Now, if the effect of any given rate of cooling is different in the cases of the carbide and graphite diagrams, it will clearly affect their relative positions, so that they will intersect at some other point than the stable position; that is, the point Q will be moved, with all the important consequences, and the relative stabilities of the two forms of carbon will be altered. Rapid rates of cooling will move Q to the right, increasing the carbide stability, both above, at, and below the eutectoid range, the quantitative effect depending largely on the movement of the position of Q . As has already been shown, the effect should be most profound in the eutectoid region, so that the greater stability of carbide should first take the form of an increase in pearlite formation; this, in fact, is in accord with experience, in that most commercial irons, which are cooled at moderate rates, conform to the graphite system at high temperatures and the carbide system at the eutectoid range, although if cooled sufficiently slowly graphite only would be formed. With still more rapid rates of cooling, pro-eutectoid cementite appears, and finally, in chilled iron, graphite formation may be completely suppressed and a completely white iron be formed. These two latter cases correspond to the movement of the point Q , first towards the eutectoid along the line HQ , and finally right up to the eutectoid line, when the austenite-cementite eutectic becomes stable.

Rate of cooling may be regarded as another variable in the system, affecting it in a manner that is qualitatively similar (though not necessarily quantitatively) to variation in silicon, an increase in the rate of cooling being structurally similar to a reduction in silicon content. In this respect, also, the author's theory appears preferable to the double diagram, which can only assume a complete change from graphite to carbide stability with variation in the cooling rate, and can therefore not account for the most commonly occurring cast-iron structures in which both forms of carbon are found.

The above application of the author's theory to the cast irons is not claimed to be quantitatively exact ; the amount of work required to make it so is very great ; the theory does, however, appear to offer an explanation of the main facts relating to the cast irons, for which no other theory so far advanced is adequate.

SUMMARY.

An investigation has been carried out on ternary alloys of iron containing 0 to 2 per cent. of silicon and 0 to 4 per cent. of carbon. Three diagrams, each representing the constitution of alloys containing a constant silicon content, have been constructed. It is shown that, in the ternary alloys, graphite and cementite can occur as stable phases, either separately or together, and the limits of temperature and composition within which each occurs have been determined.

The theory of the cast irons is developed with reference to the ternary equilibrium of the above alloy system, and this new theory is used to account for the principal features of commercial iron-carbon alloys.

The author has pleasure in acknowledging assistance received from Mr. T. E. Rooney, A.I.C., who is responsible for the chemical analyses of the alloys used ; he is particularly indebted to his research assistant, Mr. M. A. Wheeler, by whom the greater portion of the experimental work was carried out.

APPENDIX.

PARTICULARS OF THE ALLOYS, THEIR HEAT TREATMENT
AND THE STRUCTURES OBSERVED.

Alloy.	Particulars, &c.	Structure.
SC2	Cooling curve ingot 1100° C. for 44 hrs., slowly cooled over two to three days to, held for 24 hrs. and quenched at $\left\{ \begin{array}{l} 748^{\circ} \text{ C.} \\ 738^{\circ} \text{ C.} \\ 663^{\circ} \text{ C.}^1 \\ 635^{\circ} \text{ C.} \end{array} \right.$	$a + \text{pearlite}$ $a + \gamma$ $a + \gamma$ $a + \text{pearlite}$ $a + \text{pearlite}$
SC3	Cooling curve ingot 1100° C. for 44 hrs., slowly cooled over two to three days to, held for 24 hrs. and quenched at $\left\{ \begin{array}{l} 748^{\circ} \text{ C.} \\ 738^{\circ} \text{ C.} \\ 663^{\circ} \text{ C.}^1 \\ 635^{\circ} \text{ C.} \end{array} \right.$	$a + \text{pearlite}$ $a + \text{pearlite} + \text{trace X}$ $a + \text{pearlite} + \text{X}$ $a + \text{pearlite} + \text{X}$ $a + \text{pearlite} + \text{X}$
SC4	Cooling curve ingot 1100° C. for 2 hrs., slowly cooled to 850° C. ¹ and quenched 1100° C. for 1½ hrs., slowly cooled over 4 hrs. to 780° C. ¹ and quenched 1100° C. for 40 hrs., slowly cooled over two to three days to, held for 26 hrs. and quenched at $\left\{ \begin{array}{l} 765^{\circ} \text{ C.} \\ 752^{\circ} \text{ C.} \\ 730^{\circ} \text{ C.} \\ 680^{\circ} \text{ C.}^1 \\ 760^{\circ} \text{ C.}^1 \end{array} \right.$	$a + \text{pearlite}$ $a + \gamma$ $a + \gamma$ $a + \gamma$ $a + \gamma + \text{pearlite}$ $a + \text{pearlite} + \text{X}$ $a + \text{pearlite} + \text{X}$ $a + \gamma + \text{few traces pearlite}$
SC5	Cooling curve ingot 1100° C. for 44 hrs., slowly cooled over two to three days to, held for 24 hrs. and quenched at $\left\{ \begin{array}{l} 748^{\circ} \text{ C.} \\ 738^{\circ} \text{ C.} \\ 663^{\circ} \text{ C.}^1 \\ 635^{\circ} \text{ C.} \end{array} \right.$	$a + \text{pearlite}$ $a + \gamma$ $a + \gamma$ $a + \text{pearlite}$ $a + \text{pearlite}$
SC6	Cooling curve ingot 1100° C. for 44 hrs., slowly cooled over two to three days to, held for 24 hrs. and quenched at $\left\{ \begin{array}{l} 748^{\circ} \text{ C.} \\ 738^{\circ} \text{ C.} \\ 663^{\circ} \text{ C.}^1 \\ 635^{\circ} \text{ C.} \end{array} \right.$	$a + \text{pearlite}$ $a + \gamma + \text{little pearlite}$ $a + \text{pearlite} + \text{X}$ $a + \text{pearlite} + \text{X}$ $a + \text{pearlite} + \text{X}$

¹ Vacuum pumping continuous throughout experiment.

Alloy.	Particulars, &c.	Structure.
SC7	Annealed for 2 hrs. at $950^{\circ}\text{C}.$ ¹ 1100° C., slowly cooled $850^{\circ}\text{C}.$ ¹ (4 hrs.) to, and quenched $780^{\circ}\text{C}.$ ¹ at	γ γ (graphite on surface) γ + traces of graphite (little surface graphite)
	1100° C. for 48 hrs., slowly cooled over 48 hrs. to, held for 40 hrs. and quenched at $780^{\circ}\text{C}.$ ¹ $752^{\circ}\text{C}.$ $730^{\circ}\text{C}.$	γ + graphite (little surface graphite) a + graphite + pearlite (surface graphite) a + pearlite + trace graphite + X (?)
	Annealed 1100° C., slowly cooled to $950^{\circ}\text{C}.$ and quenched; reheated to $730^{\circ}\text{C}.$ for 18 hrs. and quenched	a + spheroidal Fe_3C
	1100° C. for 44 hrs., slowly cooled over 40 hrs. to $765^{\circ}\text{C}.$, held for 20 hrs. and quenched	γ + islands of pearlite (surface graphite)
	1100° C. for 24 hrs., slowly cooled over 24 hrs. to, and quenched at $760^{\circ}\text{C}.$ ¹ $680^{\circ}\text{C}.$ ¹	a + γ + graphite + Fe_3C a + graphite + Fe_3C
SC8	1100° C. for $2\frac{1}{2}$ hrs., slowly cooled over $2\frac{1}{2}$ hrs. to, held for 15 mins. and quenched at $780^{\circ}\text{C}.$ ¹ $650^{\circ}\text{C}.$ ¹	γ + Fe_3C network a + pearlite + Fe_3C network
	Cooling curve ingot	Pearlite + trace Fe_3C needles
	1100° C. for 44 hrs., slowly cooled over two to three days to, held for 24 hrs. and quenched at $748^{\circ}\text{C}.$ $738^{\circ}\text{C}.$ $663^{\circ}\text{C}.$ $635^{\circ}\text{C}.$	γ + network Fe_3C + (pearlite islands ?) a + Fe_3C network + pearlite a + graphite + pearlite a + Fe_3C (pearlite) + graphite (surface graphite)
SC9	Cooling curve ingot	Pearlite + trace Fe_3C
	1100° C. for $2\frac{1}{2}$ hrs., slowly cooled over $2\frac{1}{2}$ hrs., held for 15 min. at $650^{\circ}\text{C}.$ and quenched at $780^{\circ}\text{C}.$ ¹ $650^{\circ}\text{C}.$ ¹	γ + Fe_3C network a + Fe_3C network and pearlite (little graphite on surface)
	1100° C. for 44 hrs., slowly cooled over two to three days to, held for 24 hrs. and quenched at $748^{\circ}\text{C}.$ $738^{\circ}\text{C}.$ $663^{\circ}\text{C}.$ $635^{\circ}\text{C}.$	a + graphite + pearlite (graphite on surface) a + graphite + pearlite (graphite on surface) a + graphite + pearlite a + pearlite + little graphite (graphite on surface)

¹ Vacuum pumping continuous throughout experiment.

Alloy.	Particulars, &c.	Structure.
SC10	Annealed 2 hrs. at 1100° C. and quenched	γ
	Annealed 2 hrs. at 1100° C. and slowly cooled to, and quenched at	γ + few traces of graphite γ + graphite (surface graphite) γ + graphite (surface graphite)
	1100° C. for 48 hrs., slowly cooled over 48 hrs. to, held for 40 hrs. and quenched at	γ + graphite (trace surface graphite) α + graphite + traces pearlite (surface graphite) α + graphite (surface graphite) α + γ + graphite
	24 hrs. at 1100° C., slowly cooled over 24 hrs. to, held for 18 hrs. and quenched at	α + graphite + little pearlite (little surface graphite) α + graphite (little surface graphite)
	Cooling curve ingot	Pearlite + trace Fe_3C
SC11	Cooling curve ingot	Large needles Fe_3C + pearlite
	1100° C. for 44 hrs., slowly cooled over two to three days to, held for 24 hrs. and quenched at	γ + graphite (little surface graphite) α + pearlite + γ + graphite (?) $(\alpha + \text{graphite}) + \text{pearlite}$ (surface graphite) α + graphite + trace pearlite
SC12	Cooling curve ingot	Pearlite + Fe_3C needles
	1100° C. for 44 hrs., slowly cooled over two to three days to, held for 24 hrs. at, and quenched at	$(\alpha + \text{graphite}) + \text{Fe}_3\text{C}$ (pearlite) $(\alpha + \text{graphite}) + \text{pearlite}$ α + graphite + trace pearlite (?) $(\alpha + \text{graphite}) + \text{pearlite}$ (traces) ?
SC13	Cooling curve ingot	Pearlite + Fe_3C
	Annealed 2 hrs. at 1100° C. ¹ and quenched	γ

¹ Vacuum pumping continuous throughout experiment.

Alloy.	Particulars, &c.	Structure.
SC13	Annealed 2 hrs. at 1100° C., slowly cooled to 950° C. ¹ and quenched	γ + traces graphite as colonies
	1100° C. for 44 hrs., slowly cooled over 44 hrs. to 765° C., held for 20 hrs. and quenched	a + γ + graphite (surface graphite)
	24 hrs. at 1100° C., slowly cooled over 24 hrs., held for 18 hrs. and quenched at $\left\{ \begin{array}{l} 760^\circ \text{C.}^1 \\ 680^\circ \text{C.}^1 \end{array} \right.$	a + graphite (graphite in crack and on surface) a + graphite (surface graphite)
SC14	Cooling curve ingot	Graphite + pearlite + Fe ₃ C needles
	1100° C. for 44 hrs., slowly cooled over two to three days to, held for 24 hrs. and quenched at $\left\{ \begin{array}{l} 748^\circ \text{C.} \\ 738^\circ \text{C.} \\ 663^\circ \text{C.}^1 \\ 635^\circ \text{C.} \end{array} \right.$	γ + graphite a + γ + graphite + little pearlite a + graphite a + graphite + little pearlite (?)
SC15	Cooling curve ingot	Graphite + pearlite + few Fe ₃ C needles
	1100° C. for 44 hrs., slowly cooled over two to three days to, held for 24 hrs. and quenched at $\left\{ \begin{array}{l} 748^\circ \text{C.} \\ 738^\circ \text{C.} \\ 663^\circ \text{C.}^1 \\ 635^\circ \text{C.} \\ 730^\circ \text{C.}^1 \end{array} \right.$	a + graphite + small amount γ a + graphite + very little pearlite a + graphite a + graphite + (trace pearlite) ? a + graphite
SC16	Cooling curve ingot	Graphite + pearlite + trace Fe ₃ C
	Annealed 2 hrs. at 1100° C. and quenched	γ + graphite
	Annealed 1100° C. for 2 hrs., slowly cooled to 950° C. ¹ and quenched	γ + graphite
	1100° C. for 48 hrs., slowly cooled over two to three days to, held for 40 hrs. and quenched at $\left\{ \begin{array}{l} 752^\circ \text{C.} \\ 730^\circ \text{C.}^1 \\ 765^\circ \text{C.} \end{array} \right.$	a + graphite a + graphite a + graphite
	24 hrs. at 1100° C., slowly cooled over 24 hrs. to, held for 18 hrs. and quenched at $\left\{ \begin{array}{l} 760^\circ \text{C.}^1 \\ 680^\circ \text{C.}^1 \end{array} \right.$	a + graphite a + graphite

¹ Vacuum pumping continuous throughout experiment.

Alloy.	Particulars, &c.	Structure.
SC17	Annealed 1140° C. for 4 hrs., slowly cooled over 40 hrs. to 730° C., held for 11 hrs., ¹ and quenched	α + graphite + (trace Fe_3C)
SC18	Cooling curve ingot	Graphite + pearlite + very little Fe_3C
	Annealed 1140° C. for 4 hrs., slowly cooled over 40 hrs. to 730° C., held for 11 hrs. ¹ and quenched	α + graphite
SC19	Induction furnace, original ingot .	Graphite eutectic + little pearlite

¹ Vacuum pumping continuous throughout experiment.

DISCUSSION.

Dr. W. H. HATFIELD (Member of Council), in opening the discussion, thought that all the members who dealt with theoretical aspects of such questions must welcome the fact that the author's work would re-awaken an interest in the iron-carbon diagram. That was certainly required, because they did not possess at the present time sufficient experimental data even to attempt to draw a final diagram. A little time ago he was interested in looking for the most reliable iron-carbide diagram he could find. He turned up the new International Critical Tables and was there referred to the iron-carbide diagram produced by a distinguished member of the Institute, and found that the whole of the region with which the author dealt included the *carbide* phase. He did not believe that that could be true, but the difficulty was great because experimentally it could not be said it was not true. A decision could not be given because a perfectly pure iron-carbon series covering the whole range had not been examined and adequately investigated with regard to the stability of the carbide. It was therefore very satisfactory that the author had commenced work on the subject. On p. 132 a table of alloys was given, but quite clearly that was not a complete series of alloys for adequately tackling the job the author had undertaken, because all those alloys were under the eutectic composition. The statement was made near the bottom of p. 135 : " Fig. 26, in particular, shows clearly primary austenite grains embedded in a very fine matrix of austenite-graphite eutectic." He (Dr. Hatfield) did not believe in the existence of an austenite-graphite eutectic. If the author would study some of his (Dr. Hatfield's) papers, which he would send him, he would find at any rate very strong circumstantial evidence that the austenite-graphite eutectic did not come into existence. It was the austenite-carbide, which was the initial formation, and then the carbide decomposed. The author also used the term " graphitisation " in regard to white iron which was heat-treated to produce annealing carbon. Surely that was misleading. It was the importation of American nomenclature instead of the utilisation of the more correct German nomenclature, which spoke of such carbon as " temper " or " annealing " carbon. Temper carbon occurred in a nodular form, as distinct from the graphite so characteristic of the flaky graphitic condition. Lastly, the author spoke of the old European process as being simply one of decarburisation. It was not. It was a case of precipitation just as in the American process, the only difference being that the presence of a higher sulphur content prevented the carbide which separated at the eutectic point from dissociating. If a large number of samples were studied it would be found that in a properly decarbonised European white iron there was a graphitic content which might be as high as 2 per cent. He hoped the author would continue his attempt to make a

proper study of the system ; it must always be remembered, however, that solid metallic systems were very difficult to deal with, because difficulty was experienced in getting proper equilibrium. For instance, he might be shown a microsection which contained graphite and carbide, and therefore it might be said that the two phases were in equilibrium at a given temperature. Probably it was nothing of the kind. It might be the case that carbide breaking down set up a pressure which suppressed further dissociation. In his opinion that was a more simple explanation than the one which the author had put forward.

Mr. J. H. WHITELEY (Saltburn-by-the-Sea) said he was inclined to agree with the view set forth by Professor Hanson in his very interesting paper. It had seemed to him for many years past that it was possible to have both graphite and cementite as stable phases in iron under certain conditions, and Professor Hanson's view that these conditions arose where the two systems iron-graphite and iron-cementite interlocked was a very feasible one. The only criticism he desired to advance was in regard to a statement at the bottom of p. 138 : " It will be observed that the eutectoid point in the iron-cementite system occurs at a lower carbon content as the silicon is increased." Now, he had looked carefully through Table II. and he could find only one alloy with a composition anywhere near the eutectoid composition, namely, the alloy SC9 containing 0.82 per cent. of carbon. Moreover, in Figs. 1, 2, and 3 Professor Hanson had drawn the line $C'H$ in each case through a single point. It was obvious that these few observations were insufficient. He hoped Professor Hanson had other data in mind when he wrote the statement quoted above ; a generalisation based on such scanty data as given was clearly open to criticism.

Dr. M. L. BECKER (Manchester) thought the paper contained a reasoned hypothesis concerning the constitution of iron-carbon-silicon alloys over a range of composition which was particularly interesting from the practical point of view. The most important suggestion, and the one upon which the whole scheme seemed to depend, was to the effect that iron carbide was stable, and not graphite, below a certain temperature. Referring to Fig. 14 of the paper, that temperature was represented by the point Q . Although he knew that Fig. 14 was really a section of the ternary diagram, it was clear that in the binary diagram for the pure iron-carbon system the point Q must appear in more or less the same position as that shown in Fig. 14. Even with 0.5 per cent. of silicon there was quite a large range over which carbide was shown as stable and, if the author's hypothesis were correct, one could only infer that, in the absence of silicon, the extent of that range would be even greater. It seemed to him that there was evidence that carbide was unstable within such a range just as it was above and below it. From the results of his own experiments as well as from those of others, he had found that the carbon vapour pressure of carbide was greater than that of graphite at any given temperature within a range proved

to exceed 500°C . to 1050°C . They might therefore assume that graphite would be the more stable phase. Any attempt to explain the anomalies which had been so frequently noted in connection with the cooling and graphitisation of cast iron was extremely useful at the present time, but for the moment he felt critical as to the suggested stability of iron carbide.

CORRESPONDENCE.

Mr. E. ADAMSON (Sheffield) wrote: With the experience which Dr. Hanson has had in investigations, any research coming from him requires careful consideration. His short experience, however, in the world of cast iron has already taught him what is the general experience, that this material is by no means a simple alloy of iron and carbon.

In his present work he has made the same error as other investigators have done before the complexity of the problem became apparent to them, namely, of trying to draw conclusions from purely laboratory experiments, which it is now generally admitted in the world of cast iron have frequently little application in works practice. Upon these laboratory results he attempts to build a bridge between carbon alloys which are distinctly steels and those which are admittedly cast iron. So far no one has attempted to draw a distinct line in carbon contents between what should be called steel and what can be termed cast iron.

To illustrate the difference between laboratory alloys and works products it is not necessary to go further back than my paper on "Temperature Influences on Carbon in Pig Iron"¹ in 1911, where a virgin pig iron containing approximately 4 per cent. of total carbon and 1 per cent. of silicon was selected from the regular make of one of the West Coast blast-furnaces, and an "alloy" of practically the same carbon and silicon contents was made up from Swedish white iron and high-grade ferro-silicon. Incidentally, in his laboratory work the author states it was necessary to make an alloy of approximately 20 per cent. silicon. In works practice it was totally unnecessary to make such an alloy to introduce 1 per cent. of silicon into Swedish white iron.

The actual carbon and silicon contents were as follows:

	<i>Virgin Pig Iron.</i>	<i>Alloy.</i>
	%	%
Total carbon . . .	4.20	3.90
Graphitic carbon . . .	3.62	Trace
Combined carbon . . .	0.58	3.90
Silicon . . .	1.02	1.04
Fracture before cooling curves were taken . . .	Open No 1.	Practically white
Fracture after cooling curves were taken . . .	{ Porous grey "draws." ² }	Close grey

¹ *Journal of the Iron and Steel Institute*, 1911, No. II. p. 86.

² Confirming works practice.

Dr. Carpenter took cooling curves of these samples at Manchester, where a melting temperature of 1500°C . could be obtained. This temperature was desired, because it was thought that the higher the temperature to which the two samples were taken on melting, the greater would be the opportunity for all the carbon in each iron to go into solution, and if so both samples should produce cooling curves conforming to the carbon equilibrium diagram. In spite of the fact, however, that the temperature selected was 1500°C ., which is considerably above that of daily foundry practice, the whole of the carbon in the virgin pig iron did not go into solution, which was admitted by Dr. Carpenter, and hence produced a cooling curve which did not conform to the carbon equilibrium diagram. Some of Gonterman's cooling curves also confirm this. The second cooling curve from what was practically white iron—the "alloy"—owing to the small quantity melted having been thrown on to the iron plates of the furnace shop floor, did conform to the diagram. In short, the virgin pig iron did not conform to the equilibrium diagram, whilst the practically synthetic "alloy" did.

Incidentally, the finishing fractures both conform to works practice. The virgin pig iron was a very open No. 1 iron; engineering castings made therefrom would have been "drawn," which was exactly the case with the sample on cooling after the curve was taken. The "alloy" was solid both at the start and finish.

It may interest Dr. Hanson to know that many experiments have been made by those who are daily handling cast iron, and the experience is that if ferro-silicon is added to white iron and allowed to cool normally the fracture will be close-grained, *i.e.* small graphite flakes, regardless of the percentage of silicon added; whether this be hyper- or hypoeutectic, if normally cooled the graphite will never reach the large flake stage found in a No. 1 virgin pig iron.

These two curves confirmed me in my opinion already formed and based on actual works practice, that all the free carbon in certain grades of virgin pig iron, *i.e.* certain commercial pig irons, did not go into solution. Piwowarsky's recent American Foundrymen's paper¹ confirms this 1911 statement of mine.

Next Dr. Hanson appears to ignore such ascertained works facts as just described, and also the results of strictly scientific investigations which have a direct bearing on the influence of carbon in pig iron, both in the lower and in the higher percentages, *i.e.* in steel and cast iron. For instance, he claims the stability of the carbide, yet in everyday practice in Sheffield it is well known that under certain conditions of forging high-carbon *steel* the carbon can be precipitated as a function of forging only, even if no silicon is present.

As far back as 1864 Percy published experiments in which he obtained nothing but iron and graphite, although this was on a

¹ *Transactions of the American Foundrymen's Association*, 1926, vol. xxiv. p. 914.

laboratory scale. Ruff and Goecke,¹ in their paper on the solubility of carbon in iron, have shown that the higher the temperature to which iron is taken in contact with carbon, not only the higher is the total carbon, but *even on rapid cooling* by chilling and on a laboratory scale, graphite appeared in their specimens, which fact I have also confirmed by chilling molten blast-furnace metal in water. This is in keeping with the work of Saniter² (*loc. cit.*, p. 120), where he showed that the longer the iron is maintained in the molten condition the greater is the percentage of graphite on cooling. These results were again on a laboratory scale.

Dr. Hanson admits, on p. 157, that commercial pig irons are not usually in a condition of complete equilibrium, and he suggests, amongst other things, the rate of cooling as another variable influencing the carbon, but he does not refer to the possibility of Moissan's conclusions as to the stability of intumescent graphite formed at high temperatures and thus directly influencing the application of the equilibrium diagram to the cooling of virgin pig irons produced at high temperatures. Is this because he has no laboratory evidence? It is works evidence, however, which counts.

In short, it is my considered opinion, based on long observation of works practice, that each temperature has its own equilibrium. This must be applied primarily to the temperature at which the iron is produced, and afterwards to the temperature to which the iron is raised before a cooling curve is taken.

There have been so many theories put forward with regard to cast iron based on insufficient data, usually only laboratory data, that it is considered essential to point out some of the pitfalls which do not appear to have occurred to academic investigators. If the author continues his researches into works problems he will find that cast iron is a much more complex problem than would appear from purely laboratory experiments.

It is my opinion that considerable modifications will have to be made in the carbon equilibrium diagram before it can be of any value in works practice, but not on the lines indicated by the author. Suggestions have been made to me privately by a very eminent scientist, who has also works experience, with the greater part of which I concur, but for the moment it is premature to ask for the publication of this diagram.

In his detailed explanations of the various sections of the equilibrium diagram, Howe's verdict is "not proven." No doubt he realised that it is possible to obtain almost any structure according to the temperature and rapidity of chilling, but such unnatural structures do not, and cannot represent the carbon condition of the metal—*i.e.* percentage and exact condition of precipitated carbon and carbon still in solution—at the temperature from which chilling has taken place. Cooling

¹ *Metallurgie*, 1911, vol. viii. p. 417.

² *Journal of the Iron and Steel Institute*, 1897, No. II. p. 115.

pressures come into action, particularly that of rapid cooling, the investigation of which in cast iron is only in its infancy.

The only fairly safe conclusions which can be drawn from work done on the carbon equilibrium diagram, applied to works practice, are: (1) In certain cases of virgin pig iron, carbon can exist as free graphite in molten metal; this influences the first arrest. (2) More carbon is precipitated from solution at the graphite arrest than at any lower temperature. This arrest is usually about 1140°C. , but it may be lower under certain conditions. (3) The arrest, usually about 680°C. , shows if any carbon remains in solid solution.

Dr. A. B. EVEREST (Birmingham) wrote: At the present time progress in the development of the technique of cast iron is demanding a much fuller understanding of the principles underlying its constitution, and consequently the present paper by Dr. Hanson is to be welcomed as a great advance in the elucidation of the theory of cast iron. At first sight some of the diagrams appear terrifyingly complex, but on further study it is seen that they express in an admirably precise manner various principles now recognised by all students of cast iron.

A very simple theory of cast iron, the truth of which can scarcely be disputed, may be stated that:—the ultimate structure of the cast iron is determined primarily by only two factors—namely, (1) the relative stability of the carbide and the graphite in the iron, and (2) the thermal history of the sample of iron under consideration. It must be clearly understood that under (2) the rate of cooling of the sample from the molten state is taken into consideration, as well as any subsequent heat treatment of the casting. Under the heading of factor (1) the influences of the normal impurities, and of small amounts of alloying elements, are taken into consideration, this being justifiable, provided no new phase other than carbide or graphite becomes predominant on the addition of the special element under consideration. Thus in normal low-silicon irons the carbide is relatively the more stable phase, but on the addition of more silicon the carbide becomes less stable and more graphite is formed, provided the rate of cooling is not so high as to prevent graphite formation altogether. Under these conditions the iron becomes grey.

In the transition stage from white to grey, the stability of the carbide is very sensitive to the influence of small amounts of elements added to the iron, and by the addition of such elements the fracture may be thrown back to white, or graphite formation will be promoted and the fracture will become more grey, according to the influence of the added element on the stability of the carbide. Thus phosphorus, sulphur, manganese, and chromium, for example, render the carbide relatively more stable under normal conditions, while further additions of silicon or aluminium, nickel or copper, will promote graphite formation owing to the reduced relative stability of the carbide.

The influence of the added element on the relative stability of carbide

and graphite has been expressed by Dr. Hanson as the movement of point Q in his diagrams. Thus assuming for purposes of argument that Fig. 14 shows the true state of equilibrium in iron-carbon-silicon alloys, then the addition of any element of the first group mentioned above will move point Q up the line SE , towards E , and conversely the addition of any element of the second group will depress it towards S , resulting in the suppression of the fields containing carbide.

Confirmation of this is given in Dr. Hanson's diagrams, Figs. 4, 5, and 6, for in these diagrams Q is seen to lie successively nearer to point H (H corresponding to point S in Fig. 14), and the fields in which carbide is stable become successively smaller. These three diagrams are drawn in order, for increasing values of silicon content.

The above remarks are applied to conditions of true equilibrium in the iron. In practice such conditions (it is fairly safe to say) never pertain, although in some processes (for example, malleabilising) equilibrium conditions are very nearly approached. In ordinary cast-iron practice, however, the above remarks hold, for although rapid cooling may cause the retention of carbide in the metastable form, nevertheless under given conditions of cooling the structure will be modified as the relative stabilities of carbide and graphite are altered by the presence of impurities or of added elements.

The existence of the austenite-graphite eutectic has been greatly disputed; however, in general experimental work on cast iron, I, personally, have found structures which clearly suggest the existence of eutectic graphite. If Dr. Hanson's theory is correct (and the experimental evidence for the theory is remarkably clear, especially in the agreement between the theoretical and experimental diagrams Fig. 14 and Figs. 4, 5, and 6), then the austenite-graphite eutectic must have a definite and separate existence. However, in practice, as mentioned above, equilibrium conditions are never reached, and in the region of the eutectic temperature the cooling rate is normally so rapid that undercooling is bound to occur. Under these conditions it is logical to expect that solidification will proceed to an extent dependent on the rate of cooling, according to the metastable system (as shown in dotted lines in Fig. 11). It is for this reason that chilling will retain the iron in a white form, and investigators seeking to find graphite in samples of iron chilled from the molten state by dropping them into water find nothing (or almost nothing) but combined carbon.

Mr. J. E. FLETCHER (Dudley) wrote: The theory advanced by the author will be welcomed by all students of the metallurgy of cast iron. The effects of silicon and the influence of carbon on the structure of cooled cast-iron pieces—under variations of cooling rates such as occur in any single casting—have long been considered of paramount importance. It is of the utmost value that at last the separate and combined influence of silicon and carbon have been recognised as altering—qualitatively and quantitatively—the structure of cast irons when

cooling between the austenite-solidus line and, say, 400°C . The great utility of the theory advanced by the author lies in the fact that the reason for the presence of graphite and combined carbon together in the one cooled sample has been indicated clearly.

It has long been known that with low-silicon cast irons the carbide becomes markedly more stable over a wide range of compositions, and as this range covers most modern strong cast irons and malleable cast irons the author's definite setting out of the phases existing below Ar_1 in low, medium, and high carbon irons in Figs. 14 and 15 is most helpful practically.

The influence of high superheating of the molten ternary alloys may affect the position of the lines SX in Figs. 4 to 6, just as quenching and annealing affect them—a detail of some practical importance. The development of heat-treated cast irons must demand further knowledge of the effect of such treatment on the position of the “ $\alpha + \text{Gr} + \text{C}$ ” and the “ $\alpha + \text{Gr}$ ” phases below 700°C . The author's theory opens up the path to greater knowledge of the effects of manganese, carbon, phosphorus, and sulphur additions (particularly) to the ternary system in question, and of the influence of cooling rates, almost every casting presenting complexes inviting differential cooling rates.

It is not sufficiently recognised that the work done by the author in presenting a logically reasoned theory must be of fundamental importance in the rational advancement of cast iron metallurgical practice and research.

Mr. J. G. PEARCE (Birmingham) wrote: Controversy respecting the existence of the austenite-graphite eutectic, and whether its existence may be regarded as proved by the present paper, should not be permitted to obscure the fact that this particular structure is of considerable practical importance. Recent German work suggests that it has promising mechanical properties, but at present the structure can only be systematically obtained under cooling conditions (such as chilling), which are impracticable for general foundry operation. Any work which assists in establishing the precise conditions of composition and cooling under which the structure may be expected is of particular interest from the practical point of view. It is not at all uncommon to find austenite + fine-graphite, and ferrite + fine-graphite structures in ordinary cast iron, both chill-cast and sand-cast, light and heavy, over a fairly wide range of composition with respect to total carbon and silicon. In one case the structure has been observed in a pipe casting originally installed about eighty years ago.

The British Cast Iron Research Association particularly desires to see the investigation so ably commenced by Dr. Hanson continued and completed for ranges of silicon and total carbon found in commercial cast irons, but it should be pointed out that work of this character is costly, and the ultimate benefits through publication are shared by the steel as well as the iron industry. The complete equilibria of the iron-

carbon-silicon, iron-carbon-manganese, iron-carbon-phosphorus systems are badly needed by the industry, but the programme envisaged could only be undertaken if the Research Association had the widest possible measure of support from the industry. The complexity of composition of cast iron and its almost invariable condition of metastable equilibrium, mentioned by the author, make the practical application of such work peculiarly difficult; but it would be unfortunate if these circumstances were considered to constitute an excuse for leaving the determinations unfinished.

Mr. H. A. SCHWARTZ (Cleveland, Ohio) wrote: At first reading Dr. Hanson's paper holds out hope of accounting for the effect of elements added to the binary iron-carbon system in promoting or hindering graphitisation, more particularly in the solid state. This is written in the hope that Dr. Hanson may be persuaded to enlarge in discussion upon this aspect of the subject. The writer is so far unable to see how, under Dr. Hanson's theory, on holding white cast iron (say 0.9 per cent. Si) at any constant temperature below A_1 the metal ever becomes a mixture of ferrite and graphite. It would seem that Dr. Hanson's views require the reaction to cease when the right-hand boundary of the " $\alpha + C$ " field is reached. Nor can the writer explain on Dr. Hanson's assumption how below the point Q and above A_1 a sufficiently prolonged hold can eliminate all cementite, leaving only a solid solution and graphite.

Contrary to Dr. Hanson's view, a slow cool below A_1 is not requisite, although convenient, in the blackheart industry. Maintenance for sufficient time at any constant temperature below A_1 will effect the same result, and more quickly. The author's laboratory has done much work at 720° C., for instance. In the absence of experimental evidence in support of that conclusion, the writer entertains grave doubts whether at the lower temperatures the author's heat treatments resulted in equilibria. He has frequently observed cases where some further increase of graphite occurs under similar circumstances even after 100 or more hours. If these doubts be justified, and they apply particularly in those temperature ranges where Dr. Hanson's diagram departs from the more usual ones, the entire basis for the new theory disappears.

It is not the writer's intention to reject as untenable Dr. Hanson's viewpoint, but to point out that the experimental results so far disclosed can be entirely explained on the basis of the well-established accelerating effect of both silicon content and graphite nuclei on graphitisation.

A 0.25 per cent. carbon, 0.90 per cent. silicon steel may graphitise so slowly at, say, 700° C. as to escape observation even for a period of years, while the last 0.25 per cent. "combined" carbon in an iron containing also 3 per cent. of graphite and 0.90 per cent. of silicon may disappear quite rapidly at the same temperature, having graphite present to crystallise on.

The accelerating effect of silicon, by any mechanism, will with a

given temperature and time of heat treatment produce equilibrium more readily the higher its concentration, and will hence constrict the temperature and carbon boundaries, within which equilibrium is incomplete or graphitisation has not even begun, and thus produce the results ascribed by Dr. Hanson to the new fields he has introduced into the equilibrium diagrams.

The concept that a system consisting of $\frac{1}{4}$ per cent. carbon as cementite and α -iron may be in equilibrium, but that, if to the same system there be added 3 per cent. graphite the cementite becomes unstable towards graphite, is apparently required by Dr. Hanson's conclusions, but is very difficult for the writer. Yet without it how can we explain the graphitisation of white cast iron and the lack of graphitisation of a low-carbon steel of equal silicon content?

If Dr. Hanson can clear up these difficulties by further discussion, the writer would be much gratified.

Dr. HANSON thanked those who had contributed to the discussion, and offered the following comments on the different points raised. He differed from Dr. Hatfield on the question of the existence of the austenite-graphite eutectic, which, he believed, could be formed direct without the intervention of the carbide eutectic. The cooling curves of the alloys showed only one eutectic arrest point, which could be accounted for by the austenite-graphite eutectic structure observed in the alloys; if graphite formation were preceded by the formation of the austenite-carbide eutectic two arrest points ought to be observed, the higher corresponding to the solidification of carbide eutectic, and the lower to the decomposition of the carbide. He believed that the term graphitisation was fully justified in reference to the annealing of white iron. It was now universally agreed that the carbon produced on tempering was in the graphitic form, and if, as he believed, the formation of graphite eutectic were followed by further precipitation of carbon from solid solution, also in the form of graphite, it seemed illogical to distinguish between different stages of the continuous process. He was prepared to accept Dr. Hatfield's statement regarding the European process of making malleable iron, and to believe that the higher sulphur content accounted for the greater stability of the carbide in that process than in the American process. That influence of sulphur could no doubt be accounted for in a way exactly similar to that suggested by his theory.

The composition of the eutectoid points on the different diagrams was not so closely fixed as the diagrams might suggest, although there was more evidence as to the compositions of those points than was indicated on the diagrams themselves. For example, the proportions of ferrite and pearlite in the different alloys had been taken into account in fixing the points. As Mr. Whiteley indicated, however, some further evidence would ultimately be necessary before that region of the diagram was satisfactorily mapped out.

The relative vapour pressures of graphite and carbide were clearly of importance in relation to the stability of those two phases. On the other hand, vapour pressure determinations by indirect methods did not necessarily give the kind of information that would enable a definite opinion to be formed, since in the presence of other components, such as CO and CO₂, the vapour pressures of the solid phases were dependent on the concentration of the gaseous phases, and varied with them; it could not be assumed that the vapour pressures of carbide or graphite in contact only with iron or silico-ferrite would be the same, or even in the same order, as the vapour pressures under other conditions. He knew of no method of determining vapour pressures of the phases in the simple solid ternary system.

He was very glad to have Mr. Adamson's communication, and believed that, although it was distinctly critical in character, it was made with the object of throwing further light on that very complex subject. It was desirable to say, at the outset, that laboratory experiments alone would not afford a complete solution to the problems of cast iron, and that practical works observations were just as much scientific evidence as observations made in the laboratory. Nevertheless, it must be realised that practical evidence was only of real value when the observations on which it depended had been very carefully made, and when all the factors influencing those observations were known. Many of the practical observations on cast iron were difficult to fit into any theory, since the practical conditions were so frequently insufficiently under control for them to be regarded as conclusive scientific evidence. In the present stage of knowledge of the theory of cast iron, it was hardly to be expected that any new theory would immediately account for the behaviour of cast iron under all works conditions. Nevertheless, a systematic theory that would account for a large number of careful experimental observations, and would in a general way account for many of the phenomena met with in the cast irons, would certainly be of value. So far as he was aware, no previously published theory would claim to go so far as that. It was not unreasonable to point out that there were still many anomalies in ordinary steels that were not completely accounted for by the iron-carbon equilibrium diagram, yet no one would deny the usefulness of that diagram nor the immense amount of progress in steel metallurgy that had been made possible by it. He was well aware that grey cast irons made in the cupola were in general more finely grained than irons of similar composition made by adding ferro-silicon to white iron; the differences were, in fact, frequently very striking. On the other hand, it was not certain that the differences in constitution were so great as Mr. Adamson would suggest, and if they were each permitted to attain to equilibrium conditions, the difference would probably be found to be mainly in different size, rather than in different type, of structure. He must emphasise that it would be wrong to apply his equilibrium diagrams rigidly to the structures met with in commercial

cast iron. They only claimed to indicate equilibrium conditions, which were seldom attained in commercial irons. The application of the theory to account for all the phenomena of commercial irons could certainly not be made until much further experimental work relating to the equilibrium conditions had been carried out. The fact that graphite might be formed in high-carbon steels was not necessarily contrary to his theory; that graphite formation took place in high-carbon steels particularly at the forging heat. If his diagrams were consulted, it would be seen that graphite might occur as a stable phase in alloys containing 0.4 per cent. of silicon, and as little as 1 per cent. of carbon, that graphite occurring in the higher ranges of temperature. From Figs. 4, 5, and 6 it could be seen that as the silicon was reduced the point *Q* occurred at a higher temperature, and it seemed more than likely that with a silicon content as low as 0.1 to 0.2 per cent. the point *Q* might still be below the eutectic temperature, in which case graphite could occur under certain conditions as the stable form of carbon. The evidence of the high-carbon steel, which Mr. Adamson advanced, was not therefore contrary to his theory, but at first sight would appear to confirm it. The fact that the behaviour of cast iron depended to a considerable extent on the maximum temperature to which it was heated while liquid was not disputed, and no satisfactory explanation of that fact had yet been advanced, though from the practical point of view it was urgently required. On the other hand, he doubted if there were yet evidence to show that the equilibrium in solid cast iron was primarily dependent on the temperature at which the iron was produced, and it seemed to him that such evidence could only be obtained when more of the equilibrium conditions in the solid iron was known.

He agreed with Mr. Adamson's statement that all the equilibrium diagrams of iron-carbon alloys must be regarded as "not proven." He would certainly apply the same criticism to his own diagrams, since the amount of evidence yet available was insufficient to constitute proof. The new theory, however, approached the whole matter from a new angle, that of the known laws of equilibrium in ternary systems, and it was at least satisfactory that up to the present time all the laboratory evidence that he had been able to obtain was consistent with that new theory. He hoped that it would shortly be possible to carry out more conclusive experiments, which might constitute a critical test of his views, and Mr. Adamson's comments would be of the greatest value in devising those further practical tests.

He was extremely pleased to receive Mr. Schwartz's communication, since he had followed his (Mr. Schwartz's) work on cast iron with the greatest interest. He thought that possibly some of Mr. Schwartz's difficulties arose through his interpreting the diagrams of Figs. 4, 5, and 6 in a way that was not intended. Those diagrams merely indicated the constitution of the alloys shown in the different sections, at various temperatures, and the behaviour of any individual alloy

should be considered solely with reference to the vertical line indicating the composition of that alloy. For example, in Fig. 5 all alloys containing more than 3.4 per cent. of carbon consisted entirely of α + graphite below the eutectoid range, which was indicated by the narrow field marked " $\alpha + \gamma + \text{Gr}$ "; an alloy containing $2\frac{1}{2}$ per cent. of carbon consisted of γ + graphite above the eutectoid range, α + graphite + carbide over a short range of temperature below the range, and after the temperature of the line SX was passed of α + graphite alone. Other alloys must be similarly interpreted by noting the phase fields which were intersected by the vertical line rising from the composition of the alloy. The changes that occurred during the malleabilising process could not fairly be interpreted by considering only the amount of combined carbon retained in the alloy at any one moment. For example, alloys represented on any of the sections would, on his theory, become completely transformed into α -iron and graphite on cooling if the composition vertical ran through the α + graphite field; there were many alloys of that kind amongst those investigated. Similarly, all alloys to the right of the line QY could consist, if annealed sufficiently long, of solid solution + graphite alone, and that was what the diagrams indicated. He could not understand Mr. Schwartz's difficulty in accounting for the existence of such alloys according to his theory; that difficulty could surely only be due to the wrong interpretation of the diagrams.

The concept that a system consisting of 0.25 per cent. of carbon as cementite and α -iron might be in equilibrium, but that, if to the same system there were added 3 per cent. of graphite, the cementite became unstable, was certainly required by his conclusions, and was undoubtedly indicated as a fact of practical experience. Such behaviour, while not admissible in a binary system, was most certainly possible in a ternary system, provided that no new phase were introduced by the addition of the third element. On theoretical grounds the addition of such an element as silicon could produce the effect to which Mr. Schwartz drew attention, and the fact that observations of that kind could be accounted for by the laws of ternary equilibrium justified him in putting forward the new theory. The evidence was almost incontrovertible that carbide was the stable form of carbon in low-carbon iron alloys containing no appreciable amount of other elements (including most of the commercial steels); it was also certain that in most of the commercial cast irons graphite was the only stable form of carbon. Those two facts were irreconcilable in a binary system of alloys, yet were quite possible in a ternary system.

Mr. Schwartz's comment on the structure produced by heat treatment at a lower temperature was interesting; he (Dr. Hanson) was prepared to believe that even longer annealing times than Mr. Schwartz had used might produce additional graphitisation in some of the alloys. That would involve moving the lines bounding the α + graphite + carbide phase field to the left, and further experiments might show

that that was necessary, but he very much doubted if an increase of the time of annealing would cause that field to disappear. As soon as the opportunity occurred that matter would be made the subject of further test.

It was necessary to bear in mind one very important fact, namely, that under practical conditions, particularly in connection with malleabilising treatment, the irons were heated in contact with carbon gases, CO and CO₂, and it was well known that the nature and composition of these gases had an important influence on the form of the carbon in the alloy. For example, in contact with pure CO, iron carbide was the stable form of carbon, but the presence of a certain amount of CO₂ was quite sufficient to alter the equilibrium completely and make graphite the stable modification. Evidence based upon samples heated in contact with such gaseous mixtures was not necessarily evidence bearing on his theory, since another component, oxygen, was introduced; the system immediately became a quaternary system, and the equilibrium might very well be substantially modified.

THE INFLUENCE OF NICKEL AND SILICON ON AN IRON-CARBON ALLOY.¹

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INTRODUCTION.

WITHIN the past few decades the development of steels has been very considerable, but during the same period the other large class of iron alloys, the cast irons, has been relatively little improved. It cannot, perhaps, be expected that the same degree of success will be achieved with cast irons, of which the properties are so largely influenced by the presence of graphite, as with the steels, yet it would be surprising if the application of the same methods as have been used for alloy steels should not have important effects in the cast irons. The question is one of considerable importance, since there is an urgent demand for improved properties—mechanical, chemical, and magnetic—in these materials.

Numerous attempts to improve cast irons by alloy additions have been made, with some success in all of these directions, but the advances already made are only of such a character as to lead to the belief that much more can be accomplished.

The authors have commenced an investigation into the effect of nickel as an alloying element in cast iron. Numerous investigations into the effect of nickel have been made by other workers, both in the laboratory and foundry; but whereas in some instances the addition of nickel has been advantageous, in other instances no benefit has resulted, and it seems clear that the effect of any particular percentage of nickel may vary considerably from case to case, and will be influenced by factors such as the composition of the iron, method of adding the nickel, casting conditions, &c. With a view to clearing up some of the difficulties which have been experienced, the authors have undertaken a research into the effect of nickel on cast iron.

¹ Received May 31, 1927.

In view of the complex nature of the alloys concerned, it has been thought desirable to attempt to obtain information concerning the fundamental action of nickel, by studying its effect on simple iron-carbon-silicon alloys, before proceeding to the investigation of the more complex cast irons, in which other elements always occur, and the present paper gives an account of this preliminary work. For this reason, it must be emphasised that the present paper does not claim to describe the effects of nickel on *cast iron*, but rather to furnish a more scientific basis than at present exists for the study of this major problem. On the foundation thus obtained, experiments with more complex alloys, and on commercial cast irons, have been planned and are being carried out.

A full review of previously published work on the influence of nickel and nickel-chromium in cast irons has recently been prepared.¹

MATERIALS USED.

American washed iron, of which the following is a typical analysis, was used as the basis of these experiments :

Total carbon	%
Graphite	3·7
Silicon	Trace
Sulphur	0·03
Phosphorus	0·03
Manganese	0·016
	Nil

Silicon was added as metallic silicon of 97 per cent. purity.

For adding nickel a special alloy was used. This is a proprietary article, prepared in the form of shot, containing, in addition to nickel, some silicon, iron, and carbon, and known commercially as "F" shot. It has a melting point about 200° C. lower than that of pure nickel, and is fluid at the normal casting temperatures used for cast iron and similar alloys ; it is therefore a particularly suitable form of nickel for adding to iron-carbon-silicon alloys.

The approximate analysis of the "F" shot is given as :

Nickel	%
Silicon	91·75
Iron	5·75
Carbon	1·85
	0·3

¹ *British Cast Iron Research Association, Bulletin No. 16, 1927, April, p. 14.*

Ranges of Alloys Investigated.—The alloys tested may be divided into two classes :

(a) Low-nickel alloys, corresponding to cast irons with small additions of nickel. Nickel additions from 0 to 2.5 per cent. were made at 0.5 per cent. intervals to alloys made up of washed iron with silicon added at intervals from 0 to 3.5 per cent.

(b) High-nickel alloys, made up by adding nickel at intervals from 3.5 to 15 per cent. to alloys containing initially 0, 1.2, and 3.3 per cent. of silicon, and at intervals from 15 to 40 per cent. to low-silicon iron.

EXPERIMENTAL METHOD.

Form of Test.—Two castings were made from each alloy investigated :

(1) A step bar casting (Fig. 1) having four steps each 3 in. long \times $1\frac{1}{2}$ in. wide, the steps being 1 in., $\frac{1}{2}$ in., $\frac{1}{4}$ in., and $\frac{1}{8}$ in.



FIG. 1.—Form of Step Bar Casting.

thick, this being cast in greensand moulds previously skin dried, and having the flat face 12 in. \times $1\frac{1}{2}$ in. uppermost. The metal was run from the side into the 1 in. step, a small riser being taken off the tip of the $\frac{1}{8}$ -in. step.

This form of casting was selected as giving information concerning the fluidity of the metal, the degree of chill obtained in the small sections, and the influence of thickness of section on the hardness and other properties ; it also provided metal in suitable form for micro-examination, corrosion and other tests.

(2) A bar $1\frac{1}{4}$ in. wide \times $\frac{5}{8}$ in. thick \times $3\frac{1}{2}$ in. long cast on end in greensand on to a heavy cast-iron chill, $3\frac{1}{2}$ in. in diameter \times $1\frac{3}{4}$ in. thick. This bar was subsequently split longitudinally and the depth of chill measured. To aid in splitting the bar, a small groove was cast in, along one face of the bar.

Melting Practice.—Throughout the tests the metal was melted in salamander crucibles. In the case of the low-nickel alloys,

melting was carried out in a coke-fired wind furnace, the only type of furnace available at that time. In the case of the high-nickel alloys, a gas and air-blast crucible furnace was available and was used, as it gave cleaner melts and a greater control and reserve of temperature.

It was found by calculation and experiment that six pairs of castings as described above could be obtained from one 24-lb. pot of metal. The procedure adopted throughout this work was to fix the silicon content of the pot of metal, and to make suitable additions of "F" shot sealed in an envelope between the casts to bring up the nickel content in the pot to the desired amount before casting each pair of test-pieces.

The success of this method depends on an accurate estimate of the amount of metal in the pot at any moment, so that the correct nickel addition may be made, and also on the proper control of the amount of metal in order that the same quantity is taken from the pot for each test, and that there is at the end just the correct amount of metal for the last casting and none over. By calculation and experiment these estimates were obtained with reasonable accuracy, so that the agreement between the actual and intended nickel contents, as will be shown later, was good for the most part. Losses of nickel were very small, and no allowance for loss was made in the calculations.

Silicon was added to the molten iron in the form of small lumps of 97 per cent. silicon stirred into the melt. The loss of silicon was variable; a 10 per cent. allowance for loss was made on the calculations, but the fluctuation from this amount was considerable. There was no evidence of loss of silicon between the first and last casts from any pot of metal; in fact, the silicon figure even rose slightly on account of the silicon content of the nickel "F" shot.

The temperature of the metal was taken with an optical pyrometer while the pot was still in the furnace. In each case a pouring temperature of 1320° C. was aimed at, and in the gas furnace this could easily be attained.

It was found that the step casting could easily be run with the metal at the temperature intended. Difficulty was experienced in running the $\frac{1}{8}$ -in. step only in the cases of melts made

in the coke furnace, when owing to unfavourable weather conditions the furnace was running cold.

The metal was allowed to cool overnight in the moulds, and was consequently always at room temperature when the boxes were knocked out, thus allowing constant cooling conditions for the castings.

EXPERIMENTAL RESULTS.

Analyses of Castings.—Where the alloys were machinable, drillings for analysis were taken in each case from the 1-in. step. Samples crushed in a percussion mortar were taken from the $\frac{1}{2}$ -in. step when the iron was too hard to drill.

In Tables I. to V. the estimations of carbon, silicon, and

TABLE I.—*Initial Silicon Added, Nil.*

Test No. :	00.	02.	04.	05.	06.	07.	08.	09.	010.	011.	012.	013.	014.
	%	%	%	%	%	%	%	%	%	%	%	%	%
Total carbon ..	3.63	3.59	3.55	3.42	3.55	3.45	3.18	3.10	3.01	2.83	2.73	2.50	2.11
Combined carbon	3.60	3.57	1.73	1.57	1.57	1.55	1.36	1.33	1.26	1.01	0.91	0.68	0.30
Graphitic carbon	0.03	0.02	1.82	1.85	1.98	1.90	1.82	1.77	1.75	1.82	1.82	1.82	1.81
Silicon . . .	0.01	0.07	0.16	0.14	0.21	0.29	0.47	0.56	0.85	1.35	1.53	1.86	2.58
Nickel. . . .	Trace	0.59	1.81	2.44	3.36	4.91	7.31	10.75	13.90	19.10	22.80	28.57	39.22
Nickel intended	0	1.0	2.0	2.5	3.5	5.0	7.5	10.0	15.0	20.0	25.0	30.0	42.0

TABLE II.—*Initial Silicon, 0.5 per Cent.*

Test No. :	10.	11.	12.	13.	14.	15.
	%	%	%	%	%	%
Total carbon . . .	3.68	3.60	3.62	3.58	3.62	3.53
Combined carbon . .	2.21	1.64	1.48	1.43	1.48	1.35
Graphitic carbon . .	1.47	1.96	2.14	2.15	2.14	2.18
Silicon	0.47	0.54	0.47	0.52	0.52	0.54
Nickel	Trace	0.50	1.03	1.38	1.75	2.62
Nickel intended . .	0	0.5	1.0	1.5	2.0	2.5

TABLE III.—*Initial Silicon, 1.25 per Cent.*

Test No. :	40.	41.	42.	43.	44.	45.	26.	27.	28.	29.	210.
	%	%	%	%	%	%	%	%	%	%	%
Total carbon .	3.52	3.39	3.33	3.46	3.33	3.45	3.15	3.20	3.08	2.95	2.81
Combined carbon	1.60	1.43	1.32	1.44	1.29	1.46	1.48	1.55	1.38	1.44	1.19
Graphitic carbon	1.92	1.96	2.01	2.02	2.04	1.99	1.67	1.65	1.70	1.51	1.62
Silicon . . .	1.22	1.25	1.27	1.25	1.25	1.40	1.33	1.27	1.39	1.48	1.70
Nickel . . .	Trace	0.59	1.10	1.53	2.06	2.38	3.38	4.77	7.08	9.44	13.85
Nickel intended.	0	0.5	1.0	1.5	2.0	2.5	3.5	5.0	7.5	10.0	15.0

TABLE IV.—*Initial Silicon, 2.2 per Cent.*

Test No. :	50.	51.	52.	53.	54.	55.
	%	%	%	%	%	%
Total carbon . .	3.62	3.50	3.56	3.42	3.41	3.49
Combined carbon .	1.34	1.22	1.30	1.22	1.19	1.19
Graphitic carbon .	2.28	2.28	2.26	2.20	2.22	2.30
Silicon	2.20	2.27	2.22	2.26	2.25	2.29
Nickel	Trace	0.51	0.98	1.46	1.97	2.54
Nickel intended .	0	0.5	1.0	1.5	2.0	2.5

TABLE V.—*Initial Silicon, 3.35 per Cent.*

Test No. :	60.	61.	62.	63.	64.	65.	66.	67.	68.	69.
	%	%	%	%	%	%	%	%	%	%
Total carbon . .	3.38	3.35	3.37	3.37	3.35	3.18	3.16	3.05	2.80	2.74
Combined carbon .	1.16	1.17	1.16	1.19	1.15	1.03	1.16	1.10	0.88	0.84
Graphitic carbon .	2.22	2.18	2.21	2.18	2.20	2.15	2.00	1.95	1.92	1.90
Silicon	3.34	3.33	3.32	3.32	3.35	3.34	3.42	3.43	3.52	3.65
Nickel	Trace	0.48	1.02	1.69	2.52	3.61	5.16	7.47	9.94	13.72
Nickel intended .	0	0.5	1.0	1.75	2.5	3.5	5.0	7.5	10.0	15.0

nickel only are given. The other elements were determined in a selection of alloys, representative of each pot of metal, and were

found to be constant and negligible, the average results being: sulphur 0.03, phosphorus 0.02 per cent., and manganese nil.

The tests in Series 0, Table I., were taken from three pots of metal, giving tests 00 to 05, 06 to 010, and 011 to 014 respectively. The tests in Table III. were taken from two pots of metal giving tests 40 to 45 and 26 to 210 respectively. The tests in Table V. were taken from two pots giving tests 60 to 64 and 65 to 69 respectively. Each series in the other two tables was taken from one pot of metal. The close agreement between the actual and calculated values of nickel will be noted.

The influence of nickel in graphitising white iron is brought out in the first tests in Tables I. and II.; however, except in the case of the high-silicon alloys (Table V.), the amount of carbon graphitised became almost constant at between 50 and 65 per cent., and remained between these limits on additions of nickel up to 20 per cent. Where the iron had already been rendered completely grey by its initial silicon content, small additions of nickel appeared to have little effect on the state of combination of the carbon (see Tables IV., V.). Silicon was, in general, almost constant with small additions of nickel, and showed a tendency to rise somewhat on larger additions of nickel, owing to the silicon content of the "F" shot. The total carbon fell appreciably on the addition of higher percentages of nickel.

Appearance of Castings.—Except for the first four tests in Series 0, all castings took a sharp impression of the mould. The metal showed no lack of fluidity even with the largest nickel additions, and the $\frac{1}{8}$ -in. step of the casting was run successfully, provided the pouring temperature of the iron was not below 1250° C., which is a low limit.

The skin of the castings was good. With high nickel additions (over 10 per cent.) the skin tended to become silvery white, very smooth and almost shiny, where the iron was chilled at all.

The first tests in Series 0, with very low silicon and small additions of nickel, showed the effects of sluggish metal; the $\frac{1}{8}$ -in. step was not properly run in any case, and all the corners and edges in the castings were rounded, giving the castings a baggy appearance. The addition of 1.5 per cent. of nickel gave a sharp casting, but the metal still appeared somewhat sluggish on pouring.

Fracture and Chill.—The bars cast on to the chill blocks were broken longitudinally, and the nature of the metal and degree of chill were noted.

The influence of nickel on the original iron is illustrated in Fig. 14 (Plate X.). This shows the fractures across the middle of the $\frac{1}{2}$ -in. step of the castings containing increasing amounts of nickel. Initially the iron was completely white and unsound; on adding 0.5 and 1 per cent. of nickel, it was rendered gradually more sound, and was almost completely sound on the addition

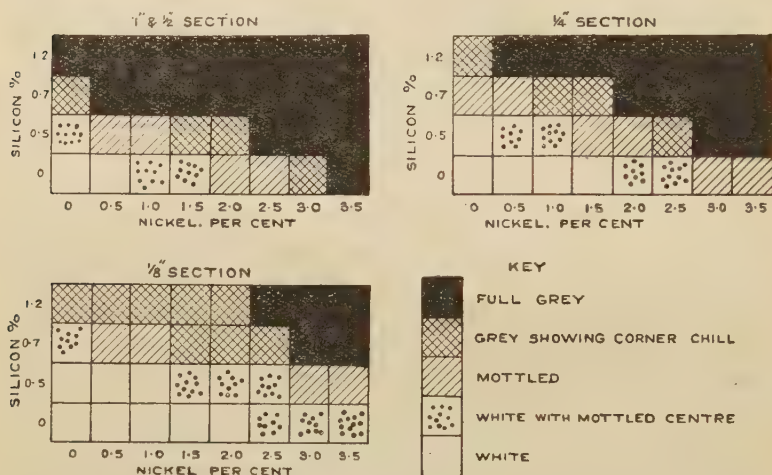


FIG. 2.—The Effect of Nickel and Silicon on Iron-Carbon Alloy Fractures.

of 1.5 per cent. of nickel. At this percentage of nickel there were a few specks of grey iron in the centre of the fracture. Further additions of nickel rendered the iron more mottled, and finally it became completely grey on the addition of 4 per cent. of nickel.

Thus the influence of nickel on this iron is seen to be similar to that of silicon, but its action was much more feeble in rendering the iron first sound, then grey. In general, to produce a given effect, four times as much nickel were required as silicon.

Fig. 15 shows a similar series of fractures obtained on adding nickel to an iron containing initially 0.5 per cent. of silicon. Fig. 16 illustrates a typical series of the fractures of the split

chilled bars, showing the effect of nickel additions between 3.5 and 15 per cent. to the original iron.

Fig. 2 presents in diagrammatic form the natures of the fractures of the various thicknesses of steps in the step bar castings of the series showing chill.

Table VI. and Figs. 3, 4, and 5 show the actual measurements of the depth of chill on the series containing 0, 0.5, and 1.2 per cent. of silicon with increasing nickel. The complete analyses

TABLE VI.—*Depth of Chill.*

(a) Initial Silicon, Nil.								
Test No. :	00.	04.	05.	06.	07.	08.	09.	010.
White	in. All	in. 1	in. 0.75	in. 0.6	in. 0.4	in. 0.25	in. 0.17	in. 0
White and mottled .	...	2	1.25	1.0	0.7	0.5	0.25	0
(b) Initial Silicon, 0.5 per Cent.								
Test No. :	10.	11.	12.	13.	14.	15.		
White	in. 0.75	in. 0.70	in. 0.65	in. 0.55	in. 0.4	in. 0.35		
White and mottled .	2.0	1.5	1.3	1.0	0.8	0.5		
(c) Initial Silicon, 1.2 per Cent.								
Test No. :	40.	41.	42. ¹	43.	44.	45.	26.	27.
White	in. 0.5	in. 0.45	in. 0.47	in. 0.32	in. 0.3	in. 0.25	in. 0.2	in. 0.1
White and mottled .	0.6	0.55	0.57	0.4	0.35	0.3	0.25	0.1

¹ Pouring temperature high.

of these alloys are given in Tables I. to V. The effect of nickel in reducing the depth of chill was very marked. It will be noted that the depth of chill (white) was equal for specimens 10 and 05. The former contained about 0.5 per cent. of silicon and no nickel, and the latter about 2.4 per cent. of nickel and low silicon.

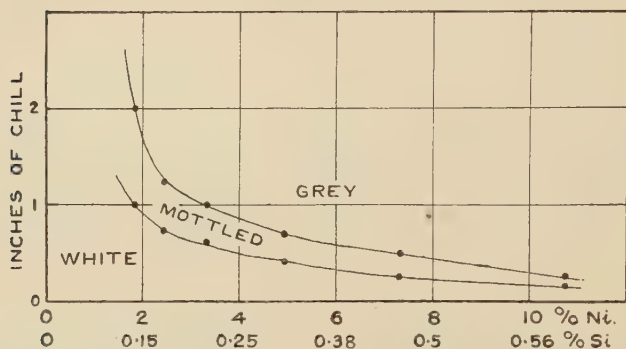


FIG. 3.—Depth of Chill. Initial silicon, Nil.

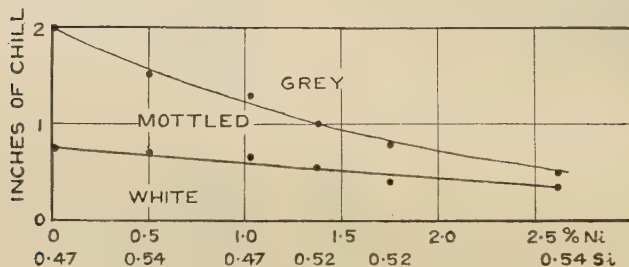


FIG. 4.—Depth of Chill. Initial silicon, 0.5%.

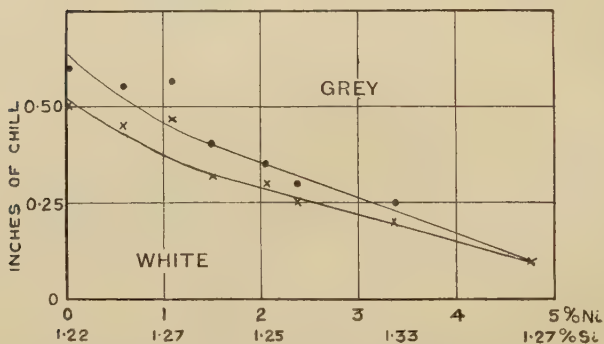


FIG. 5.—Depth of Chill. Initial silicon, 1.2%.

Again test 40 corresponded to a test in the first series, midway between 06 and 07, indicating that the sample with 1.2 per cent. of silicon was equivalent to a sample with about 4.3 per cent. of

nickel. Hence equivalent amounts of nickel and silicon are indicated as in the order of 4 to 1.

With higher silicon and nickel, white iron was entirely absent on chilling, a very fine grey fracture being obtained on chilled sections.

Microstructure of the Alloys in the Cast Condition.—For micro-examination, a specimen was cut from each casting, $\frac{1}{2}$ in. from the end of the 1-in. section, and the cut face polished. Unmachinable specimens were cut with a slitting grinding wheel, care being taken to keep the specimen as cool as possible. Micrographs were taken at corresponding points on each specimen with the specimens unetched and etched.

Influence of Nickel on the Graphite.—It has already been pointed out, under the heading of "chill," that nickel will graphitise a white iron, rendering it grey. Consequently the first effect of nickel on low-silicon iron was to increase the quantity of graphitic carbon. On adding nickel to the original washed iron, this carbon appeared first only in the small round pearlitic areas towards the centre of the specimen. On adding more nickel, these areas carrying graphite increased in size until they covered the whole specimen. This graphite was in the form of fine flakes (see Fig. 6, next page).

Eutectic graphite (fine graphite from the austenite-graphite eutectic) was seen in the specimens with over 5 per cent. nickel. The quantity of graphite, however, was nearly constant above 2 per cent. of nickel (see Table I.) throughout the remainder of Series 0.

Above 20 per cent. of nickel the graphite flakes became larger, thinner, and straighter, and approximated to the appearance of graphite in cast nickel.

If the iron were partially graphitised in the first place by a small silicon content, then, in general, the graphite present was fine. The addition of nickel to such an iron continued the graphitisation of the iron, but the graphite flakes remained in a fine form.

If, however, the initial silicon content of the iron were high enough to give coarse graphite, then the addition of nickel appeared to render the graphite flakes finer. With very high silicon (3.3 per cent.) this effect was less marked. In the case

of these irons the maximum refining of the graphite appeared at about 2.5 to 3 per cent. of nickel. As will be seen from the tables of analyses, no reduction in the quantity of graphitic carbon

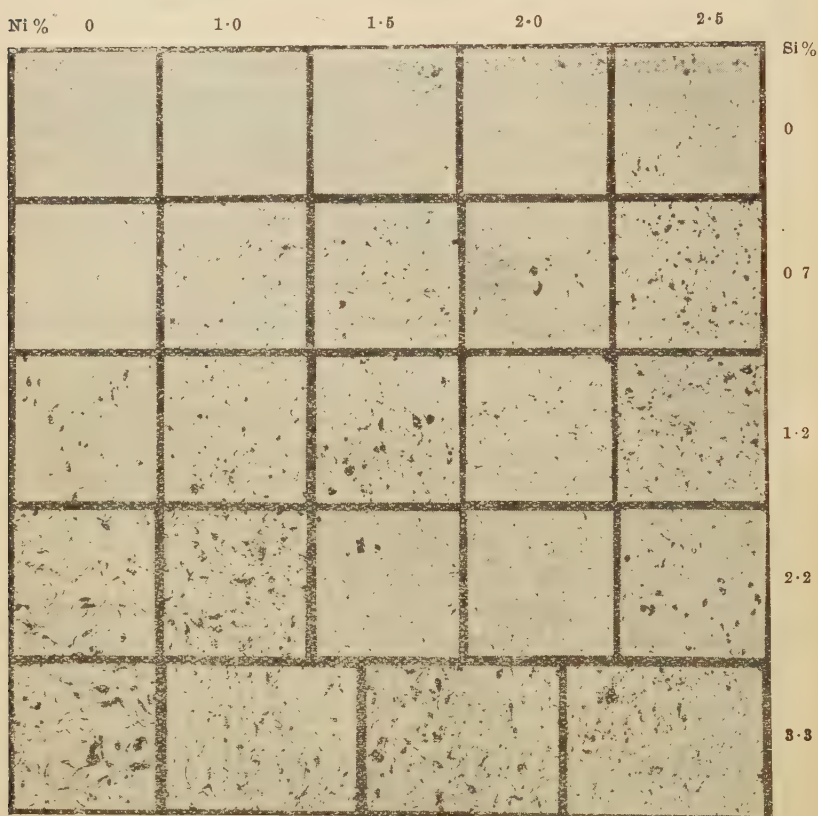


FIG. 6.—The Effect of Nickel and Silicon on Graphite. ($\times 20$.)

was obtained ; the refining consisted entirely in a reduction of the size of the flakes.

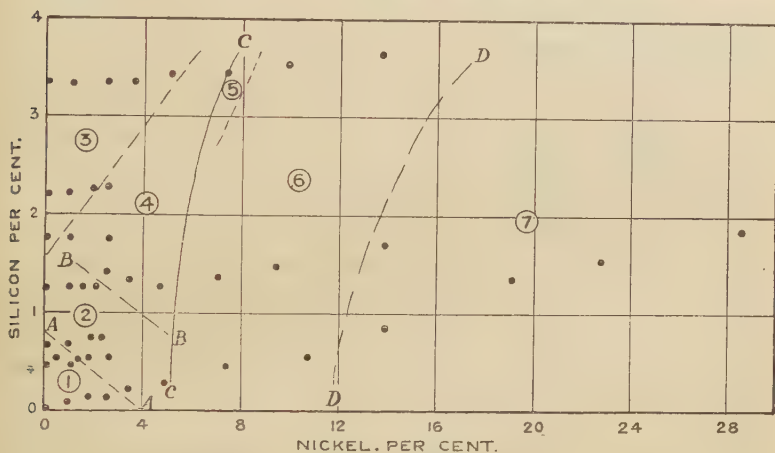
With higher additions of nickel (above 5 per cent.) fine, thin, straight flakes of graphite were obtained for all silicon contents.

General Microstructure.—Etching was carried out with a 1.5 per cent. solution of nitric acid in absolute alcohol ; one drop of a 10 per cent. solution of picric acid in alcohol was added to each 100 c.c. of the solution.

Fig. 7 shows diagrammatically the microstructure of the alloys examined, and the micrographs, Figs. 17 to 23 (Plates XI. and XII.), are typical of the different structures indicated in the diagram.

The dots show the compositions of the alloys examined.

In fields 1, 2, 3, and 4 the primary austenite in the iron had broken down to pearlite or sorbitic pearlite. In field 1, bounded



1. Pearlite + austenite-cementite eutectic.
2. Pearlite + pro-eutectoid cementite + graphite.
3. Pearlite + graphite.
4. Sorbite + graphite.
5. Martensite + graphite.
6. Martensite + austenite + graphite.
7. Austenite + graphite.

FIG. 7.—Constitution of Nickel-Silicon-Iron Alloys with 3.5% Carbon.
As cast. 1-in. section.

by the line *AA*, the structure showed the presence of austenite-cementite eutectic, corresponding to the existence of white or mottled irons. A typical example of this structure is shown in Fig. 17. The amount of the austenite-cementite eutectic decreased as *AA* was approached.

In fields 2, 3, and 4 the alloys showed pearlitic structures. In field 2 the pearlite was associated with needles of pro-eutectoid cementite and graphite, Fig. 18, the limit of existence of this type of structure, being marked at *BB* in the diagram.

In fields 2 and 4 the pearlite was very fine or sorbitic, Figs. 18

and 20. In field 3 the pearlite showed well-developed laminations, Fig. 19.

In all the alloys, as the line *CC* was approached on the addition of nickel, the pearlite became finer and more sorbitic. Beyond *CC* the structure became martensitic.

Close to *CC* alloys were found showing a completely martensitic ground-mass, Fig. 21, but beyond this narrow region the structure always showed mixed austenite and martensite, Fig. 22, with martensite decreasing as the limiting line *DD* was approached. Beyond *DD* the alloys were austenitic, Fig. 23.

A white phase of undetermined constitution, but possibly consisting of carbide, seen in Fig. 21, was associated with some of the high-silicon, high-nickel alloys, and crystals probably of carbides, as seen in Fig. 23, occurred throughout the series.

It is contrary to expectation that the principal field boundaries should curve over towards the right-hand side of the diagram. This indicates that the production of a given structure in a high-silicon alloy requires the addition of more nickel than is required to produce that same structure in a low-silicon alloy; in other words, the silicon inhibits the changes produced by the addition of nickel.

This is confirmed by a further study of the microstructures, for it is found that the structures of the following alloys correspond to each other :

Silicon, %,	0.47	1.48	3.65
Nickel, %,	7.31	9.44	13.72

Again :

Silicon, %,	0.56	1.7
Nickel, %,	10.7	13.8

And also :

Silicon, %,	1.39	3.52
Nickel, %,	7.08	9.94

It is of interest to note also that with the highest silicon contents used, and in a 1-in. section, no ferrite (except possible traces in one or two cases only amidst the pearlite) is seen. It seems possible that the production of ferrite in cast iron is profoundly influenced by the presence of elements other than silicon; comparison with ordinary cast irons would have led one to anticipate that ferrite certainly should have been formed in the

alloys investigated under the conditions of moderately slow cooling in the 1-in. section, with an iron having high total carbon and high silicon.

Influence of Nickel on Pearlite.—It was found that the addition of small amounts of nickel to an iron showing laminated pearlite caused the structure of the pearlite to become finer, and ultimately sorbitic. This effect again was masked by high silicon.

Effect on the Carbide.—The statement that nickel renders the carbide constituent more acicular cannot be confirmed, for the pro-eutectoid cementite occurring in a low-silicon iron is already in an acicular form and does not appear to be modified by the presence of nickel; as shown in Fig. 7, the quantity of this carbide is decreased by the addition of either silicon or nickel.

Machinability.—A qualitative indication of the machinability of the alloys investigated is given in the diagram, Fig. 8. The

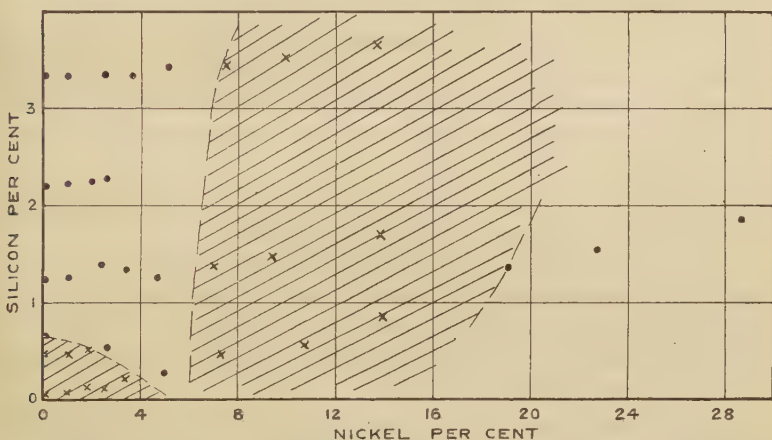


FIG. 8.—Machinability of Alloys as Cast. Shaded areas correspond to alloys not readily machinable.

diagram is based on general observations of the ease with which specimens might be cut with a hack-saw. The shaded areas correspond to the compositions of alloys not readily machinable. The area in the bottom left-hand corner of the diagram corresponds to the existence of the hard white austenite-cementite eutectic in the specimens, and the second, larger area, to the martensitic condition of the alloys.

The first area is not modified in shape by heat treatment of the iron, but the second is much diminished in size on annealing ; all specimens in this area having less than 3 per cent. of silicon became machinable on annealing for one hour at 850° C., or for six hours at 650° C. Again, certain specimens in this second area could be rendered machinable by quenching or chilling, when an austenitic structure was obtained in place of the austenite-martensite ; for example, the small sections of the casting of specimen No. 28 were much more readily machinable than were the heavier sections.

The very high nickel alloys were very soft, and could be cut with a knife. There was a slight tendency for these to drag on cutting, but the graphite present in the metal prevented this effect from becoming serious.

Hardness of Alloys.—Hardness determinations were made on all sections of each casting. After trial with various sizes of balls and various loads, a standard Brinell test using a 2-mm. ball and a load of 120 kg. was adopted, this being the largest size of test permissible on the small $\frac{1}{8}$ -in. section of the castings. The test on the 1-in. step was taken on the polished face of the microsection test-piece. The tests on the other sections were taken on the under face as cast of each step, the skin of the casting being ground away to a depth of about $\frac{1}{32}$ in.

The results of the tests on the three long series of alloys are given in the curves shown in Figs. 9, 10, and 11, and show the effect of the addition of nickel "F" shot on the hardness of each thickness of the casting. The figures given are in each case the mean of two or three determinations.

Fig. 9 shows the effect of the nickel additions on the initial iron without the addition of extra silicon. It will be noticed that in each curve there are two maxima. In the light of the micro-analysis of these series given above, the explanation of these curves is as follows :

The effect of very small additions of nickel was indefinite, owing to the unsoundness of the specimens, but as soon as the specimens were sound enough to test, a hardening action of the nickel was noticed. This was very marked on the chilled sections. In this range nickel dissolved in the alloy, but its graphitising influence, being weak, was inhibited by chilling ; under these

conditions, the nickel hardened the white iron structure (consisting principally of the austenite-cementite eutectic in this case).

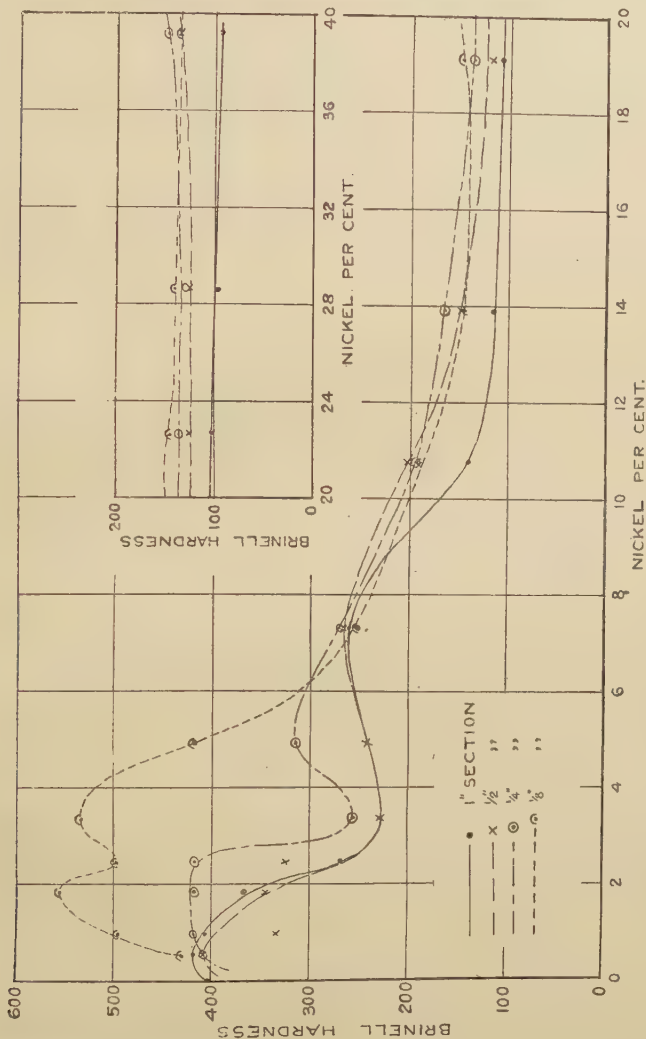


Fig. 9.—Brinell Hardness of Alloys as Cast. Series 0. Initial silicon, Nil.

This effect is the same, probably, as that noted by Hague and Turner¹ for silicon in cast iron.

¹ Hague and Turner, "The Influence of Silicon on Pure Cast Iron," *Journal of the Iron and Steel Institute*, 1910, No. II. p. 72.

As graphitisation proceeded, cementite gave place to pearlite and graphite, consequently the next portion of the curve shows a drop in hardness ; but as more nickel was added the pearlite was rendered sorbitic and then martensitic ; this change might commence before graphitisation had reached its maximum, but it always continued after graphitisation was complete, so that the hardness curve shows a rise again while the matrix of the iron was becoming harder.

On adding still more nickel, the martensitic condition of the matrix was passed, and the matrix gradually became austenitic, with a consequent fall in hardness. Once austenitic, the further addition of nickel up to 20 per cent. rendered this matrix gradually softer.

Chilling the irons in this series caused all these changes to be compressed into a small range of nickel additions. Chilling initially inhibited the formation of the graphite-pearlite structure, so that the changes started in the $\frac{1}{8}$ -in. section of the casting at a higher percentage of nickel than they did in the larger sections. Once, however, graphitisation had taken place, the effects of nickel and chill worked together to render the pearlite progressively sorbitic, martensitic, and austenitic, consequently the $\frac{1}{8}$ -in. section reached these various conditions at lower percentages of nickel than the larger sections, as shown in the curves. Moreover, when the iron was passing through the martensitic condition, moderate chill, retaining an austenitic structure, caused chilled sections to be softer and more machinable than the heavier sections. In Fig. 9, for instance, at 8 per cent. of nickel, it will be noticed that the $\frac{1}{8}$ -in. section was the softest.

The above interpretation of the shape of the curve applies to all the curves of Fig. 9. The 1-in. and $\frac{1}{2}$ -in. sections gave curves following each other closely for the small additions of nickel. The $\frac{1}{4}$ -in. section gave a curve midway between these and the $\frac{1}{8}$ -in. section curve.

It will be noted that no further changes were shown between 14 and 40 per cent. of nickel, the material being uniformly soft and showing a normal slight hardening effect of chill.

Fig. 10 shows the corresponding curves for an iron containing initially 1.2 per cent. of silicon.

These curves are of the same form as before, and the same

interpretation holds, with the exception that the initial hardening with small nickel additions is not observed, since the presence of 1.2 per cent. of silicon prevented the formation of the austenite-cementite eutectic (except in thin chilled sections), and the graphitising effect of the nickel additions became immediately effective. As is shown in Table III., the first two additions of nickel here continued the graphitisation started by the silicon, and the first effect of nickel was therefore a softening, due to this graphite formation. This was followed by the hardening of the

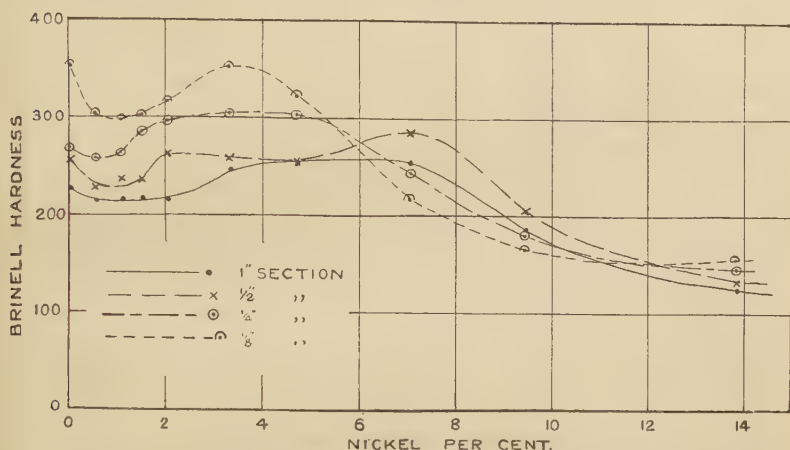


FIG. 10.—Brinell Hardness of Alloys as Cast. Series 2 and 4. Initial silicon, 1.2%.

pearlite matrix, and the subsequent soft austenitic condition as before.

The effect of chill was the same as for series 0, and it will be noted that the $\frac{1}{8}$ -in. section was the softest over a considerable range of nickel additions.

Fig. 11 shows curves for an iron with initially 3.3 per cent. of silicon. At this percentage of silicon, nickel appeared to have little effect on the comparatively coarse pearlite matrix of the iron, when added in small quantities. Finer graphite was observable, and is reflected in the curves as a hardening on the larger sections of the castings. This effect was followed by a slight softening, more marked in the smaller sections of the casting. In this

range the microstructure was a coarse pearlite, with traces of free ferrite. Further nickel, however, caused a hardening of the matrix, which changed to a martensitic form, followed by a gradual softening through austenite-martensite structures, as in the previous cases.

These curves show how, with different amounts of silicon initially in the iron, very different effects may be obtained by the addition of nickel; this may explain some of the very con-

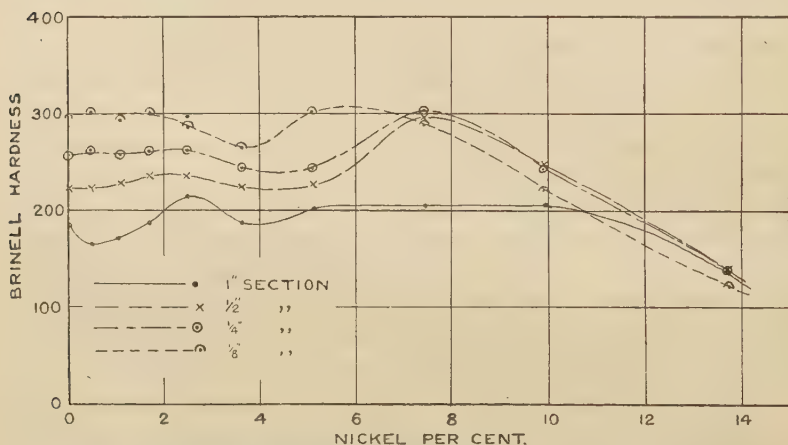


FIG. 11—Brinell Hardness of Alloys as Cast. Series 6. Initial silicon, 3.3%.

tradictory reports concerning the effect of nickel on the hardness (and other properties) of cast iron.

Magnetic Properties.—Qualitative tests only were made on the magnetic properties of the alloys. In Series 0, the low-silicon iron specimens were attracted by a magnet with decreasing intensity above 5 per cent. of nickel. The specimen with 14 per cent. of nickel was only very feebly attracted, and the specimen with 19 per cent. of nickel was almost non-magnetic. Further additions of nickel, however, up to 40 per cent., caused a progressive return of the magnetic properties in the specimens. With 1.7 and 3.6 per cent. of silicon, the specimens with 14 per cent. of nickel were still feebly attracted to the magnet.

FURTHER TESTS.

For further tests, consisting of determinations of density and resistance to corrosion and a study of the effect of annealing on the microstructure and hardness, specimens representative of the whole series of alloys investigated were selected, the selection being based on the structures of the alloys. The specimens selected were as follows :

TABLE VII.—*Specimens Representative of the Whole Series.*

No.	Nature of Alloy.	Nickel. %	Silicon. %	Density.
10	White iron	0	0.47	7.641
20	Pearlitic	0	0.66	7.372
22	"	0.96	0.68	7.363
25	"	2.36	0.74	7.351
42	"	1.10	1.27	7.353
62	"	1.02	3.32	7.211
07	Sorbitic	4.91	0.29	7.435
26	"	3.38	1.33	7.401
66	"	5.16	3.42	7.243
28	Martensitic	7.08	1.39	7.375
67	"	7.47	3.43	7.182
011	Austenitic	19.10	1.35	7.543
014	"	39.22	2.58	7.556
69	"	13.72	3.65	7.262

Density.—Specimens were cut across the $\frac{1}{2}$ -in. step of the casting and ground smooth all over, giving a test-piece approximately $1\frac{1}{2}$ in. \times $\frac{1}{2}$ in. \times $\frac{1}{2}$ in. The density determinations were made by Archimedes' method. The results, given in Table VII., call for little comment; they all lie within the limits normally given for grey and white cast irons. It will be noted that the density fell fairly rapidly as the silicon increased, whereas nickel caused only a slight decrease, followed subsequently by a gradual increase in density with larger additions. The density measurements indicate the general soundness of the alloys cast.

Resistance to Corrosion.—Samples cut from the specimens indicated in Table VII. were submitted to Mr. E. C. Dickenson, B.Met., of the British Cast Iron Research Association, who kindly conducted the corrosion tests, in which the loss per unit area on a circular face of the specimen, 1 in. in diameter, in sulphuric

acid of strengths varying between 0·5 per cent. and 20 per cent. was determined. The results show that the samples containing nickel, which had a pearlitic, sorbitic, or martensitic ground-mass, generally offered a resistance to attack in the acid inferior to that of an ordinary engineering grey cast iron. The austenitic samples showed very marked resistance, the specimens containing about 20 and 40 per cent. of nickel being practically unattacked by the strengths of acid used.

The conclusion from the tests in "normal" acid (about 5 per cent. by weight), in which solution the greatest loss of weight of the samples generally occurred, is that in a pure iron-carbon alloy containing silicon, with increasing nickel, there was a slight increase in the rate of corrosion up to 1 per cent. of nickel, with a subsequent falling off of the rate at about 2·5 per cent. of nickel, followed by another increase, until at 4 to 7 per cent. nickel the rate of corrosion was nearly twice that experienced with a good quality grey iron. On further increasing the nickel content, there was a rapid improvement in the resistance to attack, and with 15 to 20 per cent. nickel the alloy was highly resistant to sulphuric acid.

It should be remembered that the above results refer to corrosion under one set of conditions only, and it would be unwise to draw too general conclusions from them.

Influence of Annealing.—Samples, cut from the $\frac{1}{2}$ -in. step of the alloys indicated in Table VII., were used for the annealing experiments. The test-pieces were cut to $\frac{1}{2}$ in. \times $\frac{1}{2}$ in. \times $\frac{3}{4}$ in., and to reduce oxidation to a minimum they were coated with alundum cement to a thickness of about $\frac{1}{32}$ in. and dried in a steam oven. They were placed on asbestos in an electric resistance furnace large enough to ensure uniform heating of all the specimens. Temperature measurement was effected by means of a base metal thermocouple, the hot junction of which was placed in the middle of the specimens, coupled up to a millivoltmeter, and for the long test, to a thread recorder.

Two annealing experiments were conducted, each on a separate set of samples :

Test 1.—Annealing at 650° C. for about six hours ;

Test 2.—Annealing at 850° C. for one hour.

In each case the specimens were placed in the cold furnace, heated up to and held at the desired temperature for the required time, and then allowed to cool in the furnace. Heating up took about one hour in test 1 and about $1\frac{1}{2}$ hours in test 2, and cooling to room temperature took about sixteen and twenty hours respectively. When cold the specimens were cleaned, cut into two, and the inside face polished for micro-examination. The specimens were very little oxidised.

Machinability.—In Table VIII. some indication of the machinability of the specimens is given before and after annealing. It is interesting to note that, except for the original white iron, all specimens became machinable after each anneal.

TABLE VIII.—*Machinability.*

No.	Machinability.			Brinell Hardness.		
	As Cast.	Test 1.	Test 2.	As Cast.	Test 1.	Test 2.
10	Unmachinable	Unmachinable	Unmachinable	264	291	310
20	"	Machinable	Machinable	181	177	141
22	Difficult	"	"	189	170	134
25	Machinable	"	"	196	176	153
42	"	"	"	212	192	155
62	"	"	"	187	170	98
07	"	"	"	248	192	187
26	"	"	"	235	207	170
66	"	"	"	166	100	103
28	Unmachinable	"	"	235	212	119
67	"	Difficult	"	205	116	118
011	Difficult	Machinable	"	105	149	101
014	Machinable	"	"	95	79	79
69	Unmachinable	"	Difficult	130	147	153

The discussion of these results and of the hardness figures will be left until the microstructures have been considered.

Microstructures of the Annealed Specimens.—The results of micro-examinations are given diagrammatically in Figs. 12 and 13. The numbering of the fields is the same as that used in Fig. 7. In fields 1, 3, and 4 (Fig. 12) the structure was little modified on annealing at 650° C., except that the pro-eutectoid cementite was rendered globular. With nickel over 2 per cent., however, the pearlite became less stable, and on annealing tended to break

down. The first stage of breaking down was the spheroidisation of the pearlite, as shown in Fig. 24 (Plate XII.); this occurred with low-silicon alloys. With high-silicon, however, this treatment proved sufficient to cause the complete decomposition of the structure to ferrite and graphite, as shown in Fig. 25. These two micrographs correspond to the structures in fields 8 and 9 respectively.

With higher additions of nickel, martensite appeared in a state

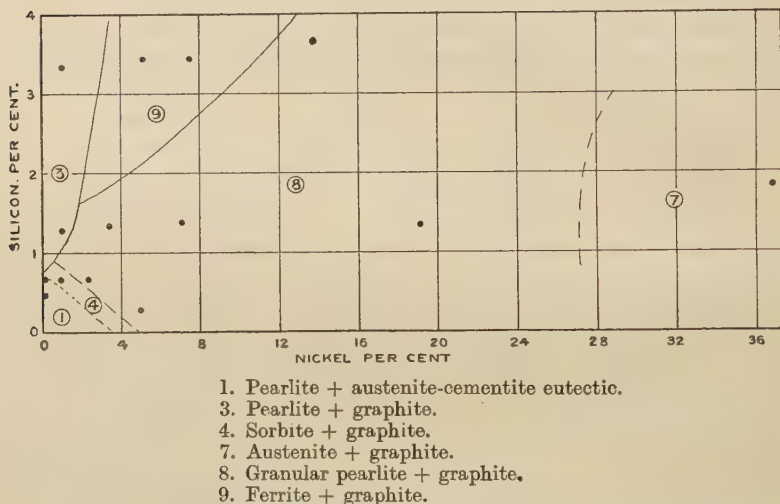


FIG. 12.—Structure of Nickel-Silicon-Iron Alloys with 3.5% Carbon. Annealed at 650° C. for six hours and cooled slowly in furnace.

of decomposition after annealing, as shown in Fig. 26. This is shown continuous with field 8, since the products of decomposition were the same as for the pearlite—namely, globular cementite and ferrite. At the high-nickel end, this field extends much farther into the austenitic field (7) after annealing.

After the higher temperature annealing, the alloys in fields 1 and 4 (Fig. 13) were found to be comparatively stable, except that the carbides tended to become globular. This is demonstrated by Fig. 27 (Plate XIII.), which shows the low-silicon alloy after annealing.

With higher silicon a field of partial decomposition of the pearlite was found (field 8), and beyond this—the major part of

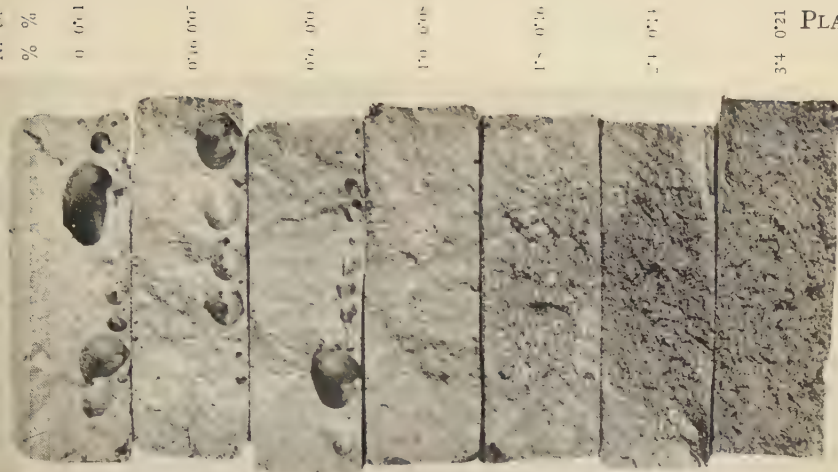


FIG. 14. — Fractures of $\frac{1}{2}$ -inch section. Initial silicon nil

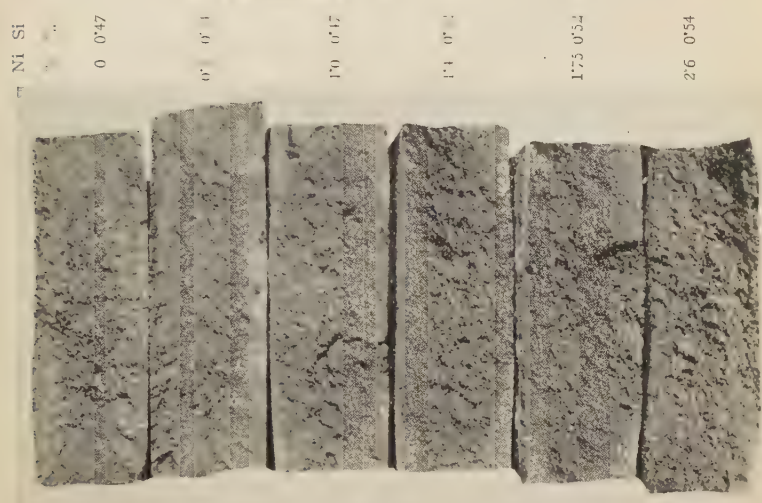


FIG. 15. — Fractures of $\frac{1}{2}$ inch section. Initial silicon 0.5 per cent.

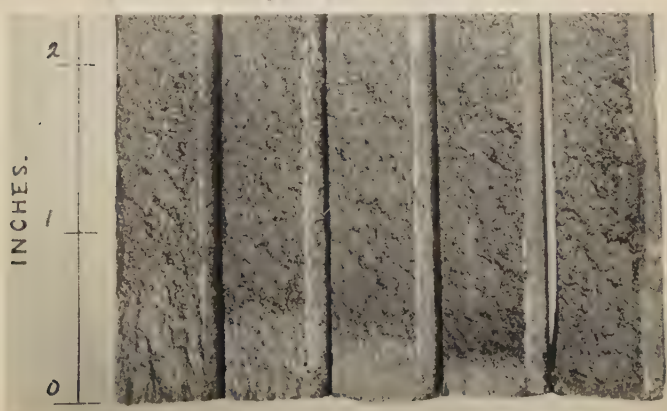


FIG. 16.—Typical series of chill bar fractures



FIG. 17.—Nickel 0.16 per cent., silicon 0.07 per cent. $\times 500$. [1.]

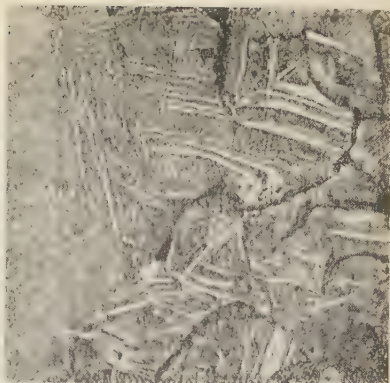


FIG. 18.—Nickel 4.91 per cent., silicon 0.29 per cent. $\times 500$. [2.]

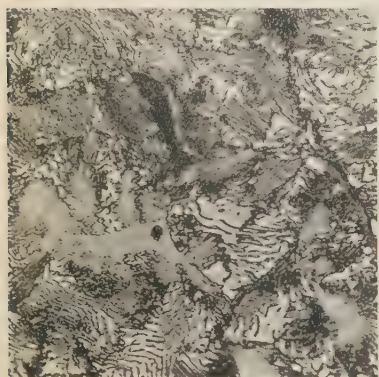


FIG. 19.—Nickel 0.98 per cent., silicon 2.22 per cent. $\times 500$. [3.]

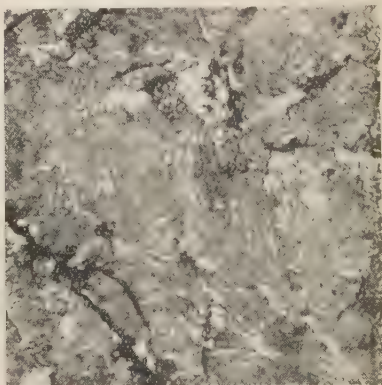


FIG. 20.—Nickel 3.38 per cent., silicon 1.33 per cent. $\times 500$. [4.]



FIG. 21.—Nickel 7.47 per cent., silicon 3.43 per cent. $\times 500$. [5.]

[The numbers in square brackets refer to Fig. 7.]

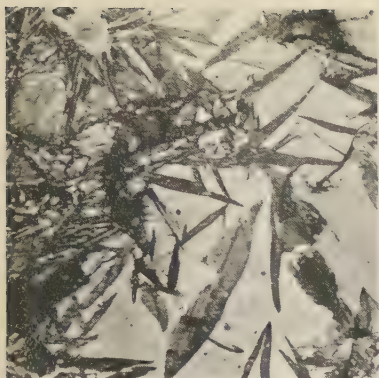


FIG. 22.—Nickel 7·08 per cent., silicon 1·39 per cent. $\times 500$. [6.]

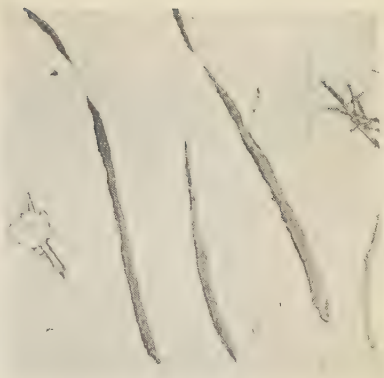


FIG. 23.—Nickel 19·1 per cent., silicon 1·35 per cent. $\times 500$. [7.]

[The numbers in square brackets refer to Fig. 7.]

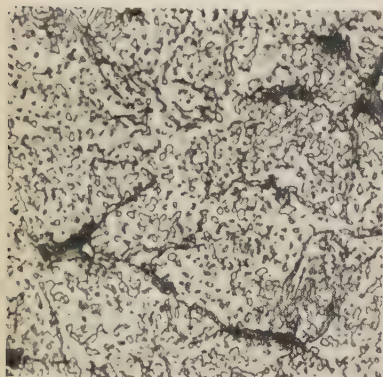


FIG. 24.—Nickel 3·38 per cent., silicon 1·33 per cent. Annealed at 850° C. for 1 hour. $\times 500$.

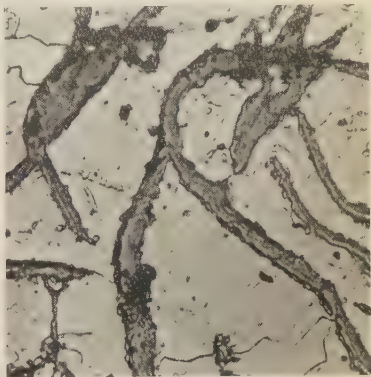


FIG. 25.—Nickel 5·16 per cent., silicon 3·42 per cent. Annealed at 650° C. for 6 hours. $\times 500$.



FIG. 26.—Nickel 7·08 per cent., silicon 1·39 per cent. Annealed at 650° C. for 6 hours. $\times 500$.

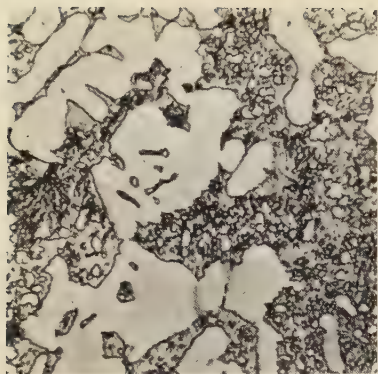


FIG. 27.—Nickel nil, silicon 0·47 per cent.
Annealed at 850° C. for 1 hour. $\times 500$.

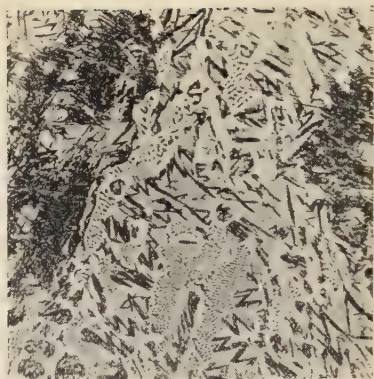


FIG. 28.—Nickel 4·91 per cent., silicon
0·29 per cent. $\frac{1}{8}$ -inch section. $\times 250$.

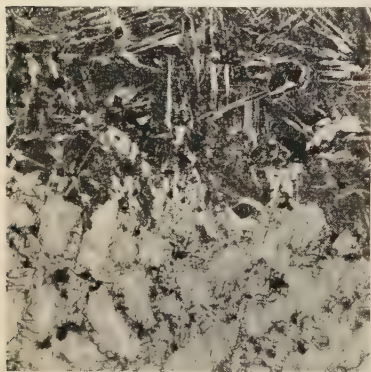


FIG. 29.—Nickel 4·91 per cent., silicon
0·29 per cent. $\frac{1}{4}$ -inch section. $\times 250$.



FIG. 30.—Nickel 10·75 per cent., silicon
0·56 per cent. $\frac{1}{8}$ -inch section. $\times 100$.

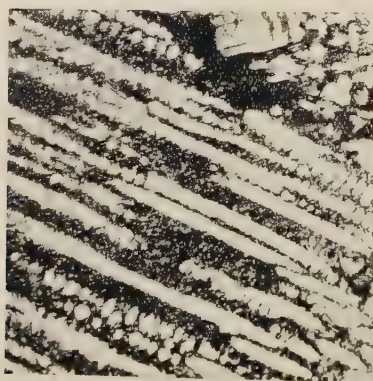


FIG. 31.—Nickel 10·75 per cent., silicon
0·56 per cent. $\frac{1}{4}$ -inch section. $\times 100$.

the diagram, a field of complete decomposition of the structure to ferrite and graphite—field 9, Fig. 25.

Specimen 69 became martensitic on this annealing, and the change was confirmed by the hardness values given by this specimen. The presence of this martensitic field (6) suggests that it must be adjacent to an austenitic field, and that there should be a zone between fields 7 and 9 somewhere in the position XY.

Fig. 13 indicates that the addition of nickel to the iron-carbon

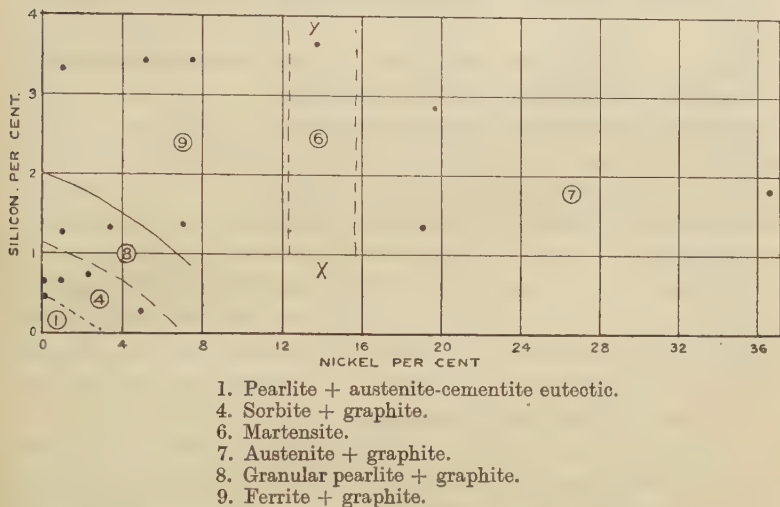


FIG. 13.—Structure of Nickel-Silicon-Iron Alloys with 3.5% Carbon. Annealed at 850° C. for one hour and cooled in furnace, taking one hour to cool to 650° C.

alloy rendered the latter less stable on annealing, but that the action of nickel was here again much more feeble than that of silicon. Specimen 07 containing 5 per cent. of nickel (and 0.3 per cent. silicon) proved comparatively stable during the second anneal, whereas specimens with 2 per cent. of silicon or over were decomposed. The direction of the field boundaries in Fig. 13 indicates that silicon and nickel produced the same effect, but that four times as much nickel was required as silicon.

In the light of these microstructures, the machinability and hardness figures in Table VIII. require, for the most part, little further explanation. For the lower nickel specimens, softening

was obtained on annealing, corresponding in general to the gradual decomposition of the structures. Round about 20 per cent. of nickel, however, annealing caused initially a breakdown of the austenite to martensite, and with further annealing the latter gradually decomposed. These specimens became harder at first, and also less machinable, and lost their non-magnetic properties. It is of interest to note that in practice irons corresponding roughly to this structure become markedly hardened on working. Table VIII. shows also, in the cases of specimens 28 and 011, that with mixtures of austenite and martensite specimens with very low Brinell hardness values might be obtained which were yet unmachinable.

Further work on the heat treatment of these alloys must be undertaken before the results are fully understood; the results reported here are intended merely to indicate the types of change obtained with specimens representative of the series of alloys investigated.

Influence of Thickness of Casting on Microstructure.—The microstructure of the thin sections of some of the castings was examined, these sections corresponding to different degrees of chill. The results are, in general, as would be expected of the influence of chill on the structures of the alloys.

As an example, specimen 07 (nickel 4.91 per cent. and silicon 0.3 per cent.) may be considered. The microstructure of the 1-in. section (Fig. 18) consisted of a ground-mass of sorbite carrying cementite crystals and graphite. At the tip of the $\frac{1}{8}$ -in. section, where chilling was most violent, an austenite-cementite structure was found, in which the austenite areas were retained in that condition or were breaking down to martensite. Towards the centre of the $\frac{1}{8}$ -in. step, the austenite-cementite eutectic occurred side by side with the austenite-graphite eutectic, while the primary dendrites of austenite were still found in the martensitic condition (Fig. 28).

In the $\frac{1}{4}$ -in. step of this casting round areas of primary austenite broken down to sorbite were found embedded in large areas of austenite-graphite eutectic with the austenite in the martensitic condition (Fig. 29).

In larger sections the specimen became completely sorbitic, Fig. 18.

Specimen 09, with 10 per cent. of nickel and 0.56 per cent. of silicon, showed in the 1-in. section a mixture of austenite with a little martensite. On chilling this specimen, the austenite was retained in all the smaller sections. In the $\frac{1}{8}$ -in. step at the tip a fine austenite-cementite eutectic structure was obtained, while in the centre of the step the austenite-graphite eutectic was in predominance; the transition structure between the two is shown in Fig. 30. In the $\frac{1}{4}$ -in. step a structure consisting entirely of primary austenite and the austenite-graphite eutectic was found (Fig. 31).

Some high-silicon specimens were examined. In them all the graphite occurred in the chilled sections in the eutectic form, the ground-mass being sorbitic, martensitic, or austenitic, according to the nickel content, and the structure in all cases being very fine.

To sum up, it may be stated that on chilling, fine dendrites of austenite were normally found associated with the austenite-cementite eutectic or with the austenite-graphite eutectic, the former eutectic being obtained with the greater chill, but not being seen in the high-silicon specimens. The austenite, both primary and eutectic, then appeared broken down to martensite or sorbite to a degree depending on the amount of chill and the nickel content of the iron. The structures obtained on chilling were always fine, and graphite occurred only in the eutectic form or in nodular areas of fine flakes (Fig. 30).

SUMMARY.

The influence of nickel and silicon on an iron-carbon alloy was investigated over ranges of nickel between 0 and 40 per cent., and of silicon between 0 and 3.6 per cent. Nickel was added to the iron in the crucible as nickel-silicon shot; the method was effective and the loss of nickel was negligible.

The original iron-carbon alloy was white and unsound. Small additions of nickel rendered this iron first sound, then grey. It was established, however, that although the action of small amounts of nickel was similar to that of silicon, nevertheless the production of a given degree of graphitisation required about four times as much nickel as silicon. Nickel, therefore, reduced the tendency of the iron to chill.

Nickel and silicon, separately or together, tended to graphitise about 50 to 60 per cent. of the carbon in 1-in. thick sand castings of this alloy. The graphite produced by the action of nickel was, in general, finer than that produced by silicon. Nickel additions to a silicon iron tended to refine the graphite. The addition of nickel tended also to produce a finer pearlite or to render it sorbitic.

Above about 5 per cent. of nickel the alloys became hard and unmachinable, due to the formation of martensite. This condition persisted up to about 18 per cent. of nickel, when the alloys became austenitic, soft, and non-magnetic, the latter property being most marked at 20 per cent. of nickel and 1.3 per cent. of silicon. Beyond 20 per cent. of nickel the alloys remained soft, but they became increasingly magnetic again.

In the presence of high silicon, more nickel was required to produce the changes of the matrix through sorbite and martensite, than in the case of low silicon. Silicon thus appeared to mask the effect of nickel.

The hardness curves for the alloys corresponded to the microstructures, showing softening during graphitisation, hardening through the sorbite and martensite ranges, and finally softening to the austenitic condition. Consequently chilling softened the alloys towards the end of the martensitic range.

The densities of the alloys examined were high for grey irons, but all lay between the limits normally given for white and grey irons.

Annealing at the proper temperatures rendered most of the unmachinable alloys machinable through the tempering of the martensite. The nickel-silicon irons were unstable on heating, but not so much so as the ordinary silicon irons. In high-nickel alloys graphite was precipitated from the austenite, which tended to become martensitic, but remained machinable.

Tests on the resistance of the alloys to corrosion in sulphuric acid showed that with small additions of nickel the alloys were more rapidly corroded than an ordinary cast iron. High additions of nickel, however, rendered the alloys austenitic, and great resistance to corrosion was shown.

The authors wish to express their appreciation of the very helpful co-operation of the British Cast Iron Research Association,

through its Nickel Committee; they would like specially to thank Mr. J. G. Pearce, B.Sc., Director of Research, and Mr. S. E. Dawson, Chairman of the Nickel Committee. They are also pleased to acknowledge the help of Mr. E. C. Dickenson, B.Met., by whom the corrosion tests were carried out. The results are published here by kind permission of the British Cast Iron Research Association.

The research has been made possible by the provision by the International Nickel Co. of Canada, Ltd., of a Research Fellowship in the University of Birmingham. This Fellowship is at present held by Dr. Everest.

DISCUSSION.

Professor C. H. DESCH, F.R.S. (Member of Council), in opening the discussion, said it was very gratifying to see that the work described by the authors had been carried so far as it had been. He had an opportunity during the spring of visiting the laboratories of the International Nickel Company in New Jersey and found that work was proceeding on the effect of nickel on cast iron, but it had not gone as far as that described in the paper. The paper afforded some accurate information as to the effect of nickel on cast iron, about which a good deal of inaccurate work had previously been published. He did not propose to attempt to criticise any of the points in detail. He presumed that the authors intended to continue with the work, because it would be particularly interesting when they dealt in future with the more complex system of nickel-chromium cast iron, which seemed to be one of the most promising materials for use at present.

Mr. T. HENRY TURNER (Birmingham) said that the paper did not claim to show the influence of nickel upon cast iron, but it was in that direction that his interest in the subject first turned. His name appeared as a co-author in friendly acknowledgment of the fact that he had happened to suggest the piece of research here dealt with, and that it had been undertaken with the aid of a generous and unconditional grant to the University which he had happened to be instrumental in obtaining. The work had been carried out by Dr. Everest, who was now working under the direction of Professor Hanson. He thought, therefore, he could best add to the discussion by saying why, in his opinion, the research had appeared to be necessary. By an examination on the spot he had satisfied himself that nickel was actually being added to commercial cast iron in the ordinary, everyday routine works practice of many of the best North American foundries, and that addition was made in relatively small percentages to high-grade cast iron. So far as he was aware, a similar practice did not exist in Europe, and the published data were so contradictory that it could not be regarded as wholly reliable. He looked round to see why that difference should exist. He noted that the Americans were using a low total carbon, by diluting their cast iron with steel scrap; that the northern irons had a low phosphorus content; and that when nickel was added it was customary to reduce the ordinary silicon content. In all the works that he visited nickel was being added in the form of a low melting-point alloy. So far as he could see, their results confirmed those obtained in the American works in so far as the combined influence of nickel and silicon were concerned, and also that nickel could be added to cast iron successfully in the form of a low melting-point alloy—nickel-silicon in that case. The latter point was worth emphasising,

because during the time in which the experiments had been carried out at Birmingham another European worker had endeavoured to add nickel to cast iron in the form of pure nickel shot placed at the bottom of the ladle, but with unsuccessful results. The difference between the success achieved at Birmingham and the failure of that other European worker might be the explanation of the varying results obtained in the experiments recorded in the literature referred to in the paper. It was hoped in the near future that further experiments would show the influence of phosphorus, chromium, and total carbon variations in conjunction with similar additions of nickel. Those results would be awaited with great interest, because in the meantime Professor Piwowarsky had published some results in a paper given at Sheffield two months ago showing that small test-pieces of cast iron could be made with a tensile strength of 47 tons per sq. in. containing approximately $3\frac{1}{2}$ per cent. of nickel and $\frac{1}{2}$ per cent. of chromium. It was in that direction, with nickel and chromium ratios approximating to those found in nickel steels, that one would expect success to be achieved so far as improved mechanical properties were concerned. Aero engines, steam engines, Diesel engines, automobile engines, electrical resistance grids, and many other special types of cast iron might not form a very big tonnage compared with cast-iron pipes, &c., but they were essential in many directions of modern engineering development, and it was in regard to that sort of high quality cast iron that he hoped the paper would prove of ultimate, if not of immediate, value.

Professor D. HANSON (Birmingham) said that reference had been made to the addition of nickel in the form of nickel-silicon alloy to cast iron, that being the way in which it was added in the work that Dr. Everest had carried out. He desired to make it quite clear that it was not suggested that that was the only way in which nickel could be added to cast iron. It was being added successfully in that way, but it was also being added quite successfully in the form of pure nickel shot to the ladle and small ingots of pure nickel through the cupola. Some people had trouble when they added nickel, but if the metal was hot enough it could be done quite successfully in that way, as it was being done not only in America but in this country. The low melting-point alloy was easier, but there was no reason to believe that if nickel were added in the pure form inferior or superior results would be obtained.

Mr. W. T. GRIFFITHS (London) corroborated Professor Hanson's statement that nickel could be added successfully to cast iron as such, as well as in the form of the shot referred to in the paper; as Dr. Hanson had said, that was actually being done in America and in this country. Apart from that point, he desired to give two warnings, especially to prospective users of nickel as an addition to cast iron in this country. The first warning was that, having heard of the successful addition

of nickel to cast iron in other countries than our own, people must not expect that it was an easy proposition to get good results immediately by adding nickel to any cast iron. As Mr. Turner had pointed out, there were certain very definite differences between the irons used across the Atlantic and those in common use in this country. Cast iron was a very complex alloy, and a considerable amount of research might be necessary before it would be possible to define the best conditions under which nickel might be added. The second warning was that, if additions of nickel to cast iron had been tried experimentally in this country, without success being immediately obtained, he suggested that the conclusion should not at once be arrived at that the addition was of no use. There were a number of factors involved, and it was work such as that put forward in the paper that would allow the members to ascertain eventually the best methods by which they could get the undoubtedly good results obtainable by adding nickel, alone and with chromium, to suitable American and English irons.

CORRESPONDENCE.

Mr. E. ADAMSON (Sheffield) wrote : The paper on " the Influence of Nickel and Silicon on an Iron-Carbon Alloy " is probably one of the best of its kind yet published. Whilst in general principles the authors come to conclusions similar to those of other workers, they have rightly realised that the actual influence of nickel will vary under different conditions ; that is, in fact, why results obtained in America cannot be strictly applied in this country.

The authors' results are obtained on what they correctly call the iron-carbon " alloy," and their conclusions can only be applied to commercial pig irons if these pig irons are, in fact, similar in general analyses *and structure* to their " alloy."

One of the most interesting points brought out in Tables I. to V. is that the addition of nickel has the general tendency to reduce the total carbon, but that is chiefly because of the increased bulk of new metal introduced. In the presence of over 1 per cent. of silicon, Tables III. to V. show that there is practically no reduction of total carbon under about 2.50 per cent. of nickel.

In their experiments the authors have come to the conclusion that the ratio of nickel to silicon is as 4 to 1, whilst in America the ratio is put forward as $2\frac{1}{2}$ to 1. The care with which their results have been carried out suggests the reliability of the authors' ratio when considering " high duty " materials.

Table VIII. is difficult to follow, as it does not appear to be arranged either by silicon or nickel contents. Can the authors give some explanation as to why, in test No. 014, the sample with a Brinell hardness of 95 is given as machinable, whilst after annealing the same metal,

with a Brinell hardness of 75, is difficult to machine? There does not appear to be any relation between Brinell hardness and machinability in any of the three tests, but there is nothing to show if this is due to nickel.

From the practical point of view Fig. 6, giving micrographs, and Figs. 14, 15, and 16, giving fractures, are perhaps the most interesting part of the paper to a practical man. Fig. 6 shows clearly that the influence of nickel itself tends to convert an otherwise white fracture into a grey fracture. In general terms also Fig. 6 shows that the general tendency of nickel is to reduce the size of the graphite flakes, otherwise to reduce grain-size, with nickel under 2.50 per cent. The exceptions are nickel 1.50 per cent., silicon 1.20 per cent., and nickel 1.00 per cent., silicon 2.20 per cent.—can the authors suggest an explanation of these last two differences?

When converting white iron to grey by the introduction of ferro-silicon under normal conditions of melting and then immediately pouring, a very open iron is never obtained, and the influence of cooling conditions—such as chilling—is greater in an “alloy” than in “commercial” pig irons of the same chemical composition, which may account for these slight differences in fracture and variations in the condition of the carbon. It is satisfactory to know that the authors have come to the conclusion that the production of ferrite is in fact influenced by the presence of elements other than silicon. As I have frequently pointed out, not only is this so, but the influence of each element present depends on whether it was present in the original pig iron or is introduced in making the alloys, as in the crucible.

Mr. W. E. DENNISON (Hull) wrote: The authors state in reviewing the results that “It is of interest to note that with the highest silicon contents used, and in a 1-in. section, no ferrite is seen. It seems possible that the production of ferrite in cast iron is profoundly influenced by the presence of elements other than silicon, &c.” May I suggest that if the authors had had more foundry experience they would have realised that the phosphorus content of commercial iron plays an important part in the graphitisation? As an example, the following two analyses are of irons cast, under similar conditions, as 40 mm. square bars.

	A.	B.
	%	%
Total carbon . . .	3.59	3.47
Graphitic carbon . . .	1.84	2.65
Combined carbon . . .	1.75	0.82
Silicon	0.86	0.86
Phosphorus	0.08	0.85
Sulphur	0.04	0.04
Manganese	0.70	0.72

Sample *A* with the extremely low phosphorus had a mottled fracture, and, in the commercial sense, was unmachinable, whereas bar *B*,

with the same silicon contents and 0.85 per cent. of phosphorus, was quite machinable. Anyone engaged continuously in foundry work is quite aware of the graphitising influence of phosphorus, as is remarked by Hurst in his "Metallurgy of Cast Iron," and yet what might be termed academic experiments always ignore the fact.

The writer respectfully suggests that future experiments should have sufficient of all of the elements occurring in commercial cast iron in the experimental base, and so make the research of industrial value. Cast iron is a complex alloy, and can only be studied as such.

Dr. E. PIWOWARSKY (Aachen, Germany) wrote: It was with great interest that I read this paper; it confirms many earlier observations, and bases upon them a number of new and important points of view. The influence of nickel, as indicated by Fig. 14, is of great interest, and I can testify from my own innumerable melting and alloying experiments that with a little practice the nickel-treated casts could be recognised with the unaided eye, as the surfaces were invariably much smoother. A point which does not appear quite evident to me from the paper is why it should be impossible to get sharp castings with low-silicon alloys in which the nickel content is less than 1.5 per cent.

Concerning the density determinations of various kinds of cast iron, the results obtained by displacement methods are of little value, as the influence of the chemical composition on the specific volume has too great an effect on the results. For the determination of the density of cast-iron alloys (that is, the determination of the degree of porosity) I have recently worked out a method in which the loss of pressure of highly compressed air, contained in a closed vessel fitted with a "window" of the cast iron, is measured; a relative value for the porosity is obtained, in a manner similar to that used for estimating the permeability of moulding sands to gas.

The importance of the experiments concerning the machinability of cast irons containing nickel cannot be sufficiently emphasised, for therein lies the greatest advantage of the addition of nickel.

It is satisfactory to note that the authors have an extension of the corrosion experiments in mind, for there also is a field in which nickel additions to cast irons have a bright prospect.

It is gratifying that the work of late years on the improvement of cast irons has been taken in hand again, and it is to be hoped that from now on really positive results may be obtained. Recent researches may be said to have solved substantially the problem of the systematic refining of graphite, so that an improvement of the metallic matrix may now be pushed much further than formerly, when the best attempts to refine the matrix were rendered abortive by the coarse structure of the graphite.

Professor T. TURNER (Member of Council) wrote that the authors, in their opening paragraph, had not given sufficient recognition to the

improvement which had taken place in cast iron during the past few decades. Fifty years ago much of the cast iron produced had a tensile strength of only 4·5 tons per sq. in., and 7 tons was considered a good average. The maximum of 15·7 tons, obtained by the writer in 1885, was at the time a record for British cast iron. In 1887 the firm of A. B. Brown of Edinburgh was able to guarantee 10 tons per sq. in. in castings for marine purposes. At present 17 tons per sq. in. is guaranteed for best cylinder castings, and it is understood that 20 tons can be obtained regularly in centrifugal castings. A record of 28·9 tons, with British iron, has actually been obtained by this method. The so-called "pearlitic cast iron" is a notable recent development. It would appear that the limit for cast irons containing only carbon, silicon, phosphorus, manganese, and sulphur has now been approached, even if it has not been reached, and this fact lends special importance to researches such as those conducted by the authors.

It may be interesting to consider upon what principles successful foundry work proceeds. Starting with a metal which possesses many of the properties which are desired, but which in its pure state is too soft, additions are made so as to make it stronger and harder, but not too hard. Speaking broadly, there are two constituents—a weak one and a hard one. Upon the blending of these success depends. The soft one, or matrix, may be strengthened by taking something into solid solution, and the brittle constituent may be caused to produce a better effect by being in a state of fine division. These principles have long been recognised, and may be illustrated by any series of commercially useful alloys, ferrous or non-ferrous. Applying these principles to cast iron, we have a soft matrix of ferrite, a hard constituent in iron carbide, and to a lesser extent in iron phosphide. There is also a foreign body, graphite, deposited throughout the mass, and causing weakness. The ferrite may be strengthened by a suitable addition of silicon and of manganese, which exist in solid solution. The good effect of iron carbide and iron phosphide are best seen when they are present in suitable quantity and in a state of fine division. The weakening effect of graphite is greatly minimised when it is in a state of fine division. In good ordinary cast iron we have already strengthened the matrix so far as the elements at our disposal will allow. We have also finely distributed our carbide, as pearlite or sorbite, uniformly distributed our phosphide, and rendered our graphite almost granular. For further advance some fresh element or elements must be added to a cast iron which is already as nearly perfect as it can be obtained.

Such additional elements are always more expensive than iron, and to employ them with metal which is not already well balanced can only lead to disappointment. There is reason to believe that there is a wide field, at present very imperfectly explored, for the use of other elements, in relatively small proportions, for the production of cast iron of the highest quality.

The most promising of these other elements is nickel, which was

successfully introduced in France, for piston rings, about twenty years ago. Nickel is now freely used by American iron-founders, but its application in this country has been delayed by want of knowledge of the circumstances in which it should be used, the way it should be introduced, and the proportions which should be employed. The present paper is a useful contribution in that it supplies some of the information needed. Nickel acts like silicon in that its addition changes white iron into grey, but its action in this respect is less marked. Hence nickel should not be employed to do what can be done effectively and more cheaply by means of silicon. It is only when silicon has already played its part that the best effects of nickel are obtained. It now strengthens the matrix (or silico-ferrite), and makes the graphite finer in texture. The authors are aware, though not coming within the scope of their present research, that when chromium is also added still better results can be obtained.

Starting with an iron with a well-balanced composition, nickel strengthens the matrix, but decomposes iron carbide, tending thus to give strength from one cause and softness from the other. Chromium acts in the opposite manner. It strengthens the matrix, but tends to increase the carbide, and thus make the metal too hard. By adding both nickel and chromium the good effects of each can be obtained, and any ill-effects may be neutralised.

The foregoing remarks refer particularly to ordinary foundry mixtures with not more than about 2 per cent. of nickel. In the higher ranges of nickel content there are special mixtures used for purposes to which the previous remarks do not apply. In such alloys certain physical and chemical properties are obtained which cannot be so readily obtained in any other way. In these directions also an increasing use of nickel in connection with cast iron may be anticipated in future.

The value of the paper would have been enhanced had it been possible to include tensile or other usual mechanical tests. Brinell hardness tests are less trustworthy as a guide in a heterogeneous material such as cast iron than with a more homogeneous material like mild steel.

The AUTHORS, in reply, desired to express their thanks to those who had contributed to the discussion. They could assure Professor Desch that the work was being continued, and a study of nickel-chromium cast iron would undoubtedly find a prominent place in the programme of future work.

Mr. Adamson referred to Table VIII.; the order of the alloys in that table was, as indicated in Table VII., that of their structures, *i.e.* from white iron, through pearlitic, sorbitic, to austenitic; in other words, it indicated the combined effect of nickel and silicon. Test-piece No. 014 (Table VIII.) was found to be machinable after all heat treatments.

Referring to Fig. 6, there appeared to be no anomaly in regard to the alloy containing nickel 1·5 per cent. and silicon 1·2 per cent.; nickel would increase both the quantity and, to some extent, the size of the graphite in a low-silicon iron, and it was generally after that initial graphite development that nickel produced its refining action. The 1·2 per cent. silicon series was a transition stage between the lower silicon series where graphite development was seen, and the higher silicon series where refining of the graphite was shown to a greater or less extent. Other variations in the series of micrographs were due to slight variations in conditions.

Mr. Dennison appeared to have missed the whole point of the paper as emphasised in the paper itself and in the discussion, namely, that it claimed to be no more than a basis for a major research on nickel in cast iron. It was generally accepted that such a basis was necessary for the full understanding of the influence of any element, and was rendered necessary by the very complexity of cast iron. Other experiments on synthetic irons with phosphorus and other additions were in hand for the same reason. The major research on nickel in cast iron was at present in progress, and was being carried out in an up-to-date foundry under normal foundry conditions and with cupola-melted iron mixtures made up from ordinary pig and scrap. That work would be reported more fully later.

With regard to the production of ferrite in the iron, the authors considered that the example chosen by Mr. Dennison, with high and low phosphorus, was unfortunate, for many workers, both foundry and academic, found the influence of phosphorus to be very irregular; often it would hinder rather than promote graphitisation. The authors had observed many samples of low-silicon irons changed from grey to white by the addition of phosphorus. The suggestion implied by the passage quoted by Mr. Dennison was, rather, that some influence, not yet recognised, such as the presence or absence of gas in the iron, was at work. In connection with that, Mr. Adamson's closing remarks were of interest.

The difficulty of obtaining sharp castings with the low-silicon nickel alloys referred to by Dr. Piwowarsky was probably due to the high freezing point of such alloys, which impaired their fluidity, coupled with too low a pouring temperature used for those series.

The density values given in Table VII. referred to the normal ratio of weight to volume used in calculations with cast iron, and were obtained by what was probably the best-known method of determining specific gravity. The authors were very interested in Dr. Piwowarsky's method of determining the degree of porosity of cast iron, although they did not think it was entirely free from objection as a method of measuring soundness.

The authors wished also to thank Professor T. Turner and Mr. Griffiths for their valuable contributions.

MAGNETIC AND OTHER CHANGES CONCERNED IN THE TEMPER-BRITTLINESS OF NICKEL-CHROMIUM STEELS.*

By H. A. DICKIE, B.Sc., Ph.D., A.R.T.C. (GLASGOW).

INTRODUCTION.

IN a paper ⁽¹⁾ presented to the Institute a year ago, Professor Andrew and the author showed the importance of the rate of cooling from the tempering temperature in revealing changes in specific volume and in hardness in nickel-chromium and other special steels. When the cooling rate was sufficiently slow to induce the fully brittle state in the steels, the specific volume and the Brinell hardness had values similar to those obtained in the same steels quenched from the tempering temperature, that is, in the tough condition. When, however, the rate of cooling was not sufficiently slow to induce brittleness in the steels, a contraction and a softening were revealed by specific volume and hardness determinations. A theory was put forward, based on the above peculiar double effect, to account for the phenomenon of temper-brittleness.

The present paper contains an account of experiments carried out to discover how the magnetic properties, the specific electrical resistance, the specific volume, and the hardness of highly susceptible nickel-chromium steels are affected by various tempering treatments. A summary of previous physical determinations by other investigators was given in the paper mentioned above ⁽¹⁾ and need not be repeated here.

The following table shows the analyses of the steels used in this investigation :

Analysis of Steels.

Steel.	Carbon. %	Silicon. %	Sulphur. %	Phosphorus. %	Manganese. %	Nickel. %	Chromium. %
AH	0.31	0.310	0.021	0.015	0.47	4.46	1.41
NC	0.31	0.145	0.029	0.026	0.57	3.20	0.83
NR3	0.36	0.275	0.021	0.016	0.34	1.90	1.15

* Received June 13, 1927.

EXPERIMENTAL METHODS.

Magnetic Tests.—These were taken by the bar-and-yoke ballistic method, full details of which may be found in Ewing's "Magnetic Induction in Iron and Other Metals." The accuracy of the apparatus was checked by the use of two specimens standardised by the National Physical Laboratory. The author's determinations on these specimens were found to agree very closely with the standard figures supplied. The specimens used for magnetic determinations were bars 1 cm. in diameter and 28 cm. in length, the clear length within the yoke being 25 cm. The test-bars were machined from $\frac{5}{8}$ in. square bars after heat treatment. Hysteresis loops for a maximum magnetising force (H) of 150 c.g.s. units were determined, and also the variation of magnetic induction (B) and remanent induction ($B_{\text{rem.}}$) from $H = 0$ to $H = 250$.

Specific Resistance.—The specimens for the determination of resistivity were about 9 cm. in length, and were machined down to 3 mm. in diameter after heat treatment. Specimens obtained from Izod impact test-pieces, being shorter than the above, were machined down to $2\frac{1}{2}$ mm. to give an actual resistance of the same order. One of the specimens was taken as a standard, and its resistance between permanently fixed knife-edges of nickel-chromium steel was determined at various room temperatures, a current of 1.5 amp. being passed through the specimen and the voltage drop between the knife-edges read on a Tinsley vernier potentiometer. The current was accurately determined by reading on the potentiometer the voltage drop across a standard resistance in the circuit. The various results, after calculation to resistivity, were plotted on a temperature-resistivity graph, and the specific resistance at 20° C. was read off. This was taken as the absolute specific resistance of the standard specimen at that temperature. The resistance of the other specimens was determined by comparison with the standard, the "unknown" being placed in the circuit across another set of knife-edges. Readings were taken on the standard before and after each reading on the unknown, and the latter was determined a number of times after moving it slightly along the knife-edges between each set of readings. For the calculation of the specific resistance the diameter of each specimen was measured at cross-diameters each

3 mm. along its length and the mean diameter taken. The distance between the knife-edges was also accurately determined. The knife-edges were screwed on a wooden block, so that they were exactly parallel to one another, and the specimens were firmly held on them by means of powerful elastic bands.

By this method the effects of variations in the current and in the temperature are eliminated, and the results are strictly accurate relative to the standard, assuming that the temperature coefficient of resistance is the same for all the specimens used. A number of tests showed that the temperature coefficient did not vary appreciably in different specimens and, as the lowest temperature of any test was 19.0°C . and the highest 21.5°C ., it may be taken that the results are of a high degree of accuracy.

Specific Volume and Brinell Hardness.—These were determined by the methods used in previous work,⁽¹⁾ the specific volume by comparison with a standard specimen by weighing in paraffin, and the hardness on an Alpha Brinell machine, using a perfectly spherical 10-mm. ball.

FIRST SERIES OF EXPERIMENTS.

It was desired to obtain specimens of the steels *AH*, *NC*, and *NR3* suitable for magnetic, resistivity, and other tests in the tough, intermediate, and fully brittle conditions, with tempering effects equalised as far as possible in all the specimens. Suitable lengths of $\frac{5}{8}$ in. square bar of each steel were subjected to the following heat treatments, use being made of the well-known phenomenon of impact reversibility.⁽²⁾

All the bars were first oil-hardened after being maintained for half an hour at 850°C .

First Treatment.—*AH*₂, *NC*₂, *NR3*₂, and *AH*₃, *NC*₃, *NR3*₃, were tempered for two hours at 660°C . and quenched in water.

Second Treatment.—*AH*₃, *NC*₃, *NR3*₃, from first treatment, and *AH*₁, *NC*₁, *NR3*₁, were tempered for two hours at 660°C . and slowly cooled at the rate of 0.3°C . per minute.

Third Treatment.—*AH*₁, *NC*₁, *NR3*₁, from second treatment, were tempered for two hours at 660°C . and quenched in water.

Fourth Treatment.—*AH*₂, *NC*₂, *NR3*₂, from first treatment, were tempered for two hours at 660°C . and slowly cooled at the rate of 2°C . per minute.

Each bar was thus tempered for a total of four hours at $660^{\circ}\text{C}.$, and was subjected to a slow cooling and to a quenching treatment from that temperature. As a result of these treatments it may be said that tempering effects were exactly equalised in the tough condition (AH_1 , NC_1 , $NR3_1$) and the fully brittle condition (AH_3 ,

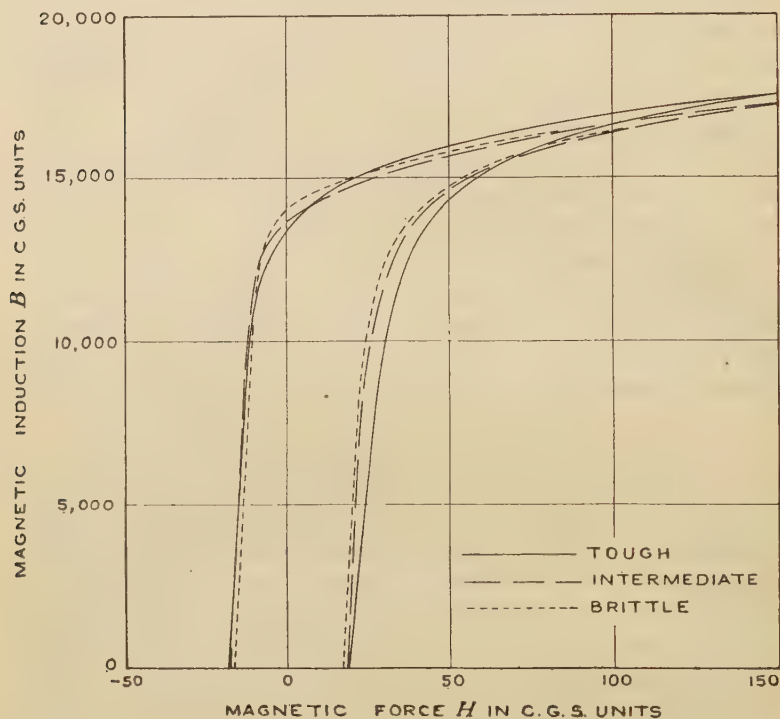


FIG. 1.—Cyclic Curves of Steel AH .

NC_3 , $NR3_3$), but that in the intermediate condition (AH_2 , NC_2 , $NR3_2$) the bars received slightly less tempering, due to the quicker rate of final cooling.

Heat treatment was carried out in an electric tube furnace wound over a length of 2 ft. The variation of temperature from end to end of the specimens was small, and the temperature at the centre was kept at exactly $660^{\circ}\text{C}.$ in the tempering treatments. This temperature was chosen to give as large changes as possible on slowly cooling.⁽¹⁾ It has been shown, however, that slight

solution in the Ac_1 range takes place at this temperature in steel AH .⁽³⁾ For the other steels this temperature is well below the start of the Ac_1 range.

After the heat treatments suitable specimens of the dimensions previously noted were machined for the various tests.

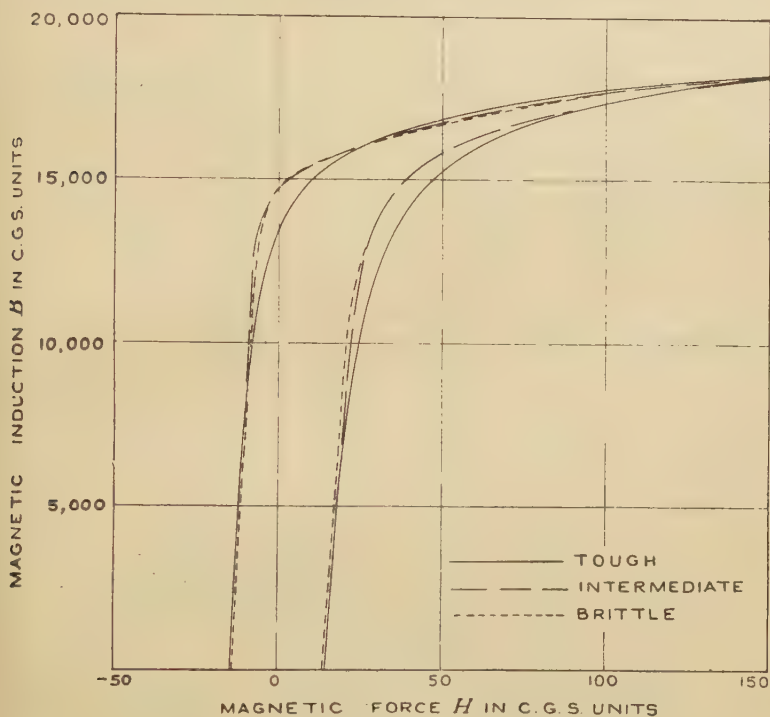


FIG. 2.—Cyclic Curves of Steel NC .

Hysteresis half-loops for a maximum magnetising force of 150 c.g.s. units are shown in Figs. 1, 2, and 3. The curves for the tough, intermediate, and brittle states of each steel have been superimposed for easy comparison. It will be seen that after the slow-cooling treatments the shape of the curves is modified in a characteristic manner, due to a rise in retentiveness and an increase in permeability at the lower values of the magnetising force. In steel AH (Fig. 1) a small amount of carbide had been dissolved in γ -iron at the tempering temperature, and the effect

of this is apparent when the magnetic properties of this steel are compared with those of the others. In steels *NC* and *NR3* (Figs. 2 and 3), in which changes in the ferrite are alone concerned, the tempering temperature having been clearly below the start of A_{c1} , the properties of the intermediate and the fully brittle

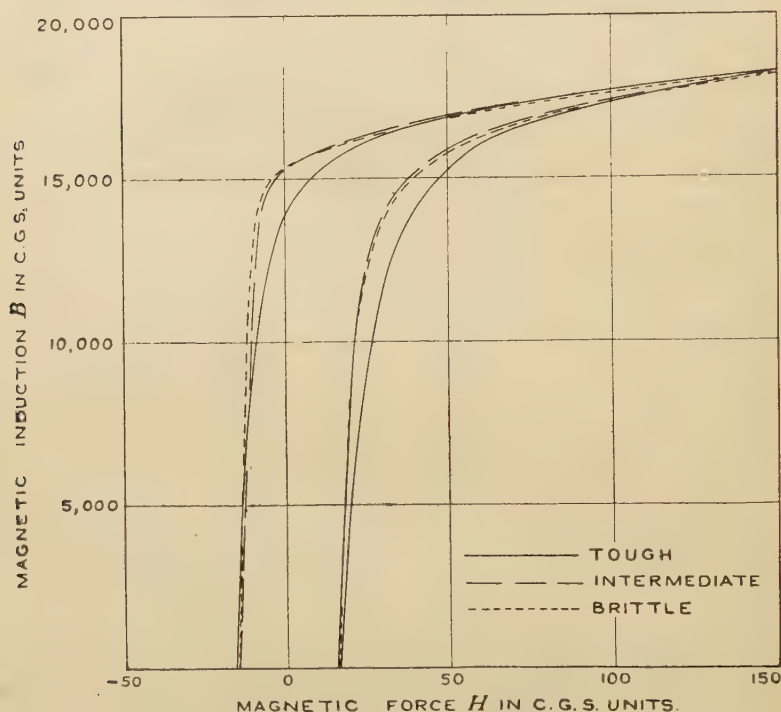


FIG. 3.—Cyclic Curves of Steel *NR3*.

specimens are very similar, and are distinctly different from those of the tough specimens.

In Figs. 4, 5, and 6 are shown curves for the variation of magnetic induction and remanent induction from $H = 0$ to $H = 250$ for the various states of each steel. Here again the similarity of the intermediate and brittle states in steels *NC* and *NR3* is very apparent. The difference between the remanence of the various states is shown more distinctly in Fig. 7, where the percentages of the maximum induction remaining as remanent

induction are plotted against the corresponding values of the magnetising force. It is seen that after the lower values of H have been exceeded the percentage of the induction remaining

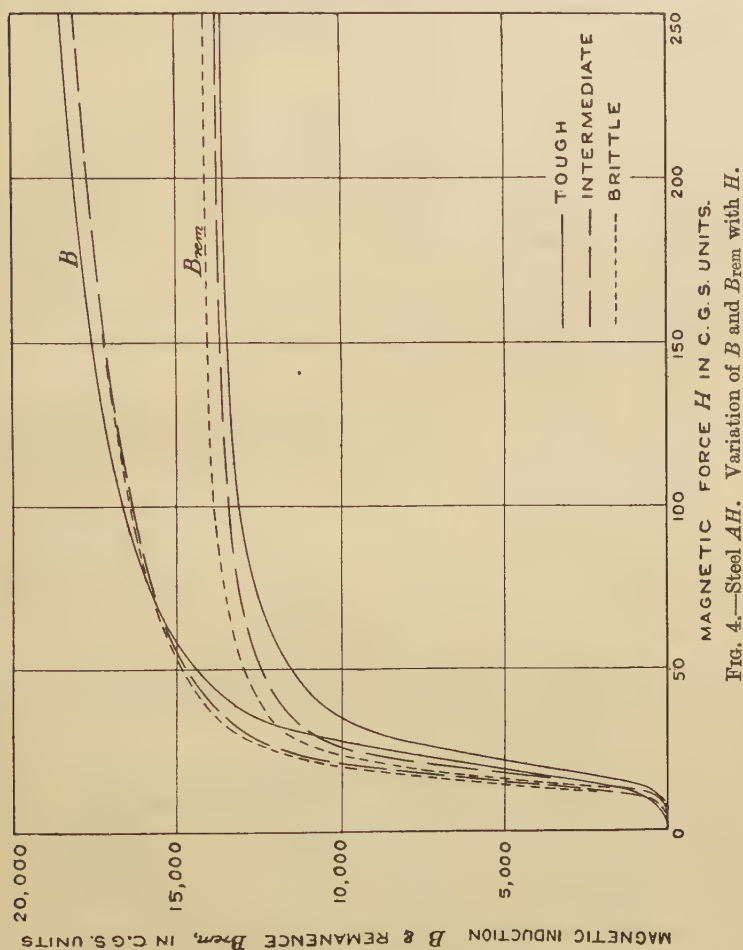


Fig. 4.—Steel AH. Variation of B and B_{rem} with H .

as remanent magnetism increases about 7 or 8 per cent. on slow cooling in steels NC and $NR3$, the total increase being somewhat less in steel AH . The variation of the permeability for the various states of each steel is plotted in Figs. 8, 9, and 10. The maximum permeability in each case rises on slow cooling, and the

maximum values of the intermediate and brittle states for the respective steels are very similar. Small differences in the maximum permeability of these two states correspond directly

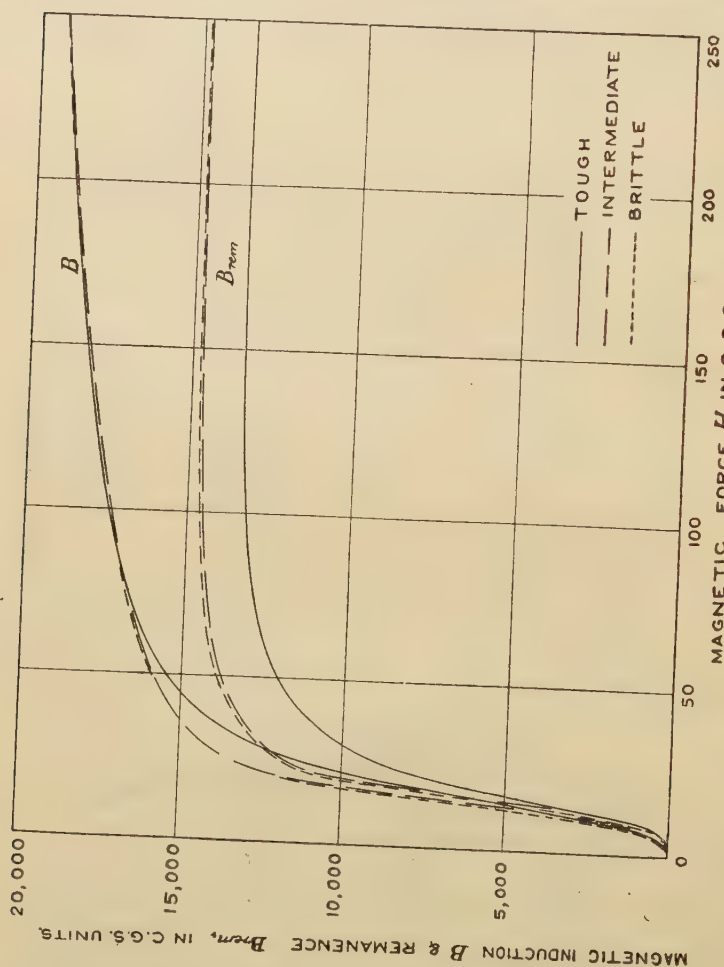


Fig. 5.—Steel No. 5. Variation of B and B_{rem} with H .

to small differences in the coercive force. (Figs. 1, 2, and 3, and Table I.)

Table I. shows a summary of the chief magnetic properties, including the hysteresis loss, calculated from the area of the hysteresis loops. It will be seen that the latter property decreases in each steel after the slow-cooling treatments.

TABLE I.—*Summary of Magnetic Properties from Hysteresis Loops for $H_{max.} = 150$ c.g.s. Units.*

Steel.	Condition.	Coercive Force, H_c .	Maximum Induction, $B_{max.}$	Remanent Induction, $B_{rem.}$	$B_{rem.} \times 100, B_{max.}$	Percentage Increase in $B_{rem.}$	Hysteresis Loss, Ergs per c.c.	Maximum Permeability, $\mu_{max.}$
AH	{ Tough .	18.5	17,540	13,400	76.4	} 3.1 } 5.2	102,000	368
	{ Intermediate .	18.0	17,180	13,660	79.5		90,600	484
	{ Brittle .	16.5	17,210	14,040	81.6		89,000	505
NC	{ Tough .	14.7	18,270	13,400	73.4	} 7.4 } 7.6	87,400	465
	{ Intermediate .	14.7	18,200	14,720	80.8		86,400	595
	{ Brittle .	14.0	18,220	14,760	81.0		82,000	614
NR3	{ Tough .	16.0	18,220	13,930	76.5	} 7.8 } 8.3	96,000	432
	{ Intermediate .	14.8	18,160	15,300	84.3		90,500	575
	{ Brittle .	15.1	18,120	15,360	84.8		92,600	558

Table II. shows the results of determinations of resistivity, specific volume, and Brinell hardness.

TABLE II.—*Resistivity, Specific Volume, and Brinell Hardness Values.*

Steel.	Condition.	Specific Resistance at 20° C. Microhms.	Decrease in Specific Resistance.	Specific Volume.	Brinell Hardness.
AH	{ Tough .	32.20	} 0.58 } 0.99	0.127735	258
	{ Intermediate .	31.62		0.127607	250
	{ Brittle .	31.21		0.127638	255
NC	{ Tough .	30.47	} 0.37 } 0.55	0.127736	252
	{ Intermediate .	30.10		0.127637	243
	{ Brittle .	29.92		0.127752	252
NR3	{ Tough .	24.23	} 0.29 } 0.54	0.127613	246
	{ Intermediate .	23.94		0.127572	238
	{ Brittle .	23.69		0.127621	248

The specific volume and Brinell hardness show in each case the double effect discovered in previous work.⁽¹⁾ In this connection it should be noted that the specimens in the intermediate condition received less tempering than the others, and consequently the difference in values, being in opposition to the contracting and softening effects of extra-tempering, is all the more significant. Also, it is certain that there is a definite rate of cooling (probably

varying in different steels, and possibly a quicker rate than that used) which would give a larger contraction and softening than that obtained in these experiments.

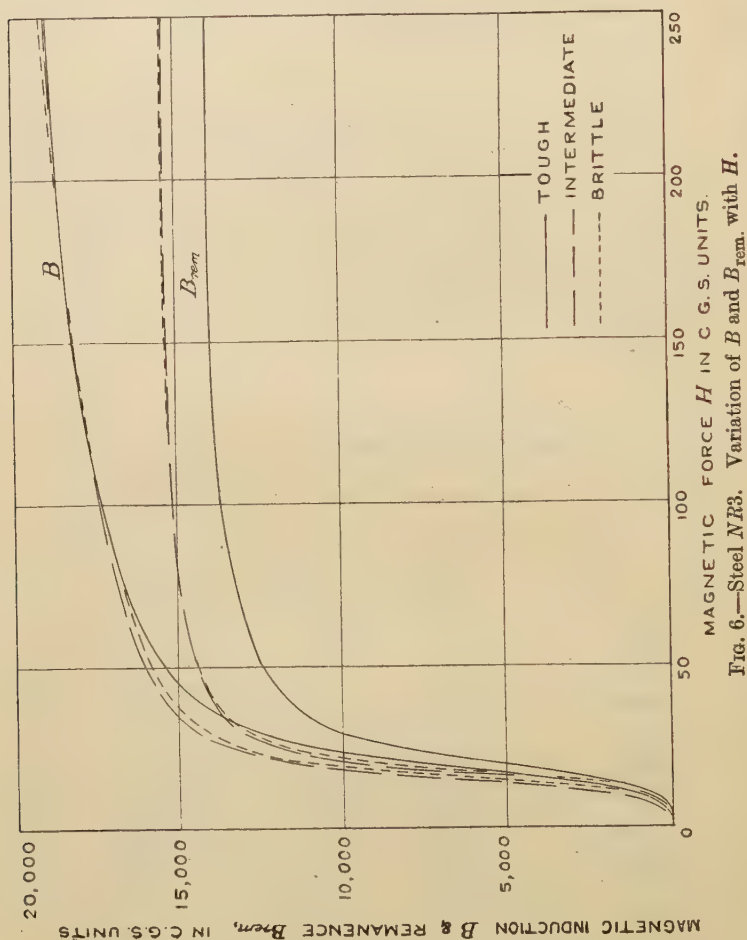


Fig. 6.—Steel NR3. Variation of B and B_{rem} with H .

The resistivity (Table II.) varies directly with rate of cooling, but it is likely that the difference in tempering effect between the 2° C. per minute and the 0.3° C. per minute rates of cooling accounts entirely for the difference in values obtained between the intermediate and brittle specimens, and that, if the

tempering effects had been exactly equalised in these two states, their resistivity would be practically equal. It has been found by Campbell and Mohr⁽⁴⁾ that even in carbon steels spheroidisation

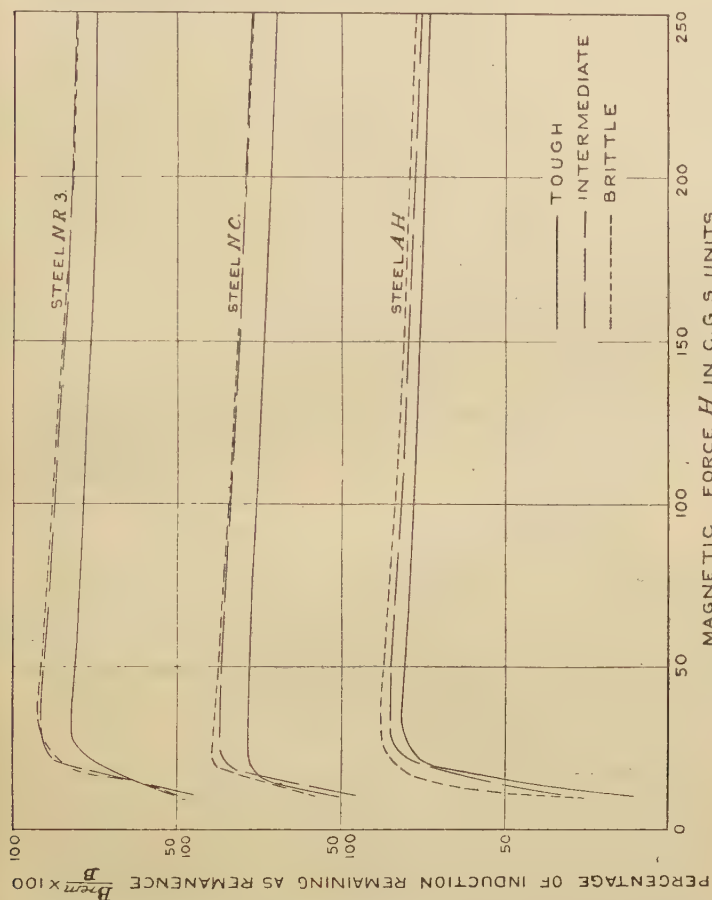


Fig. 7.—Steels AH, NC, and NR3. Variation of B_{rem} per cent. with H .

of carbides below A_{r1} , on annealing at a slow rate, may produce a decrease of 0.1 to 0.2 microhm in the resistivity when compared with the values obtained on annealing at a moderate rate. This effect may thus be expected to be apparent in the resistivity determinations in the present paper. Spheroidisation of the carbide would not, however, be expected to have an appreciable effect on the magnetic properties.

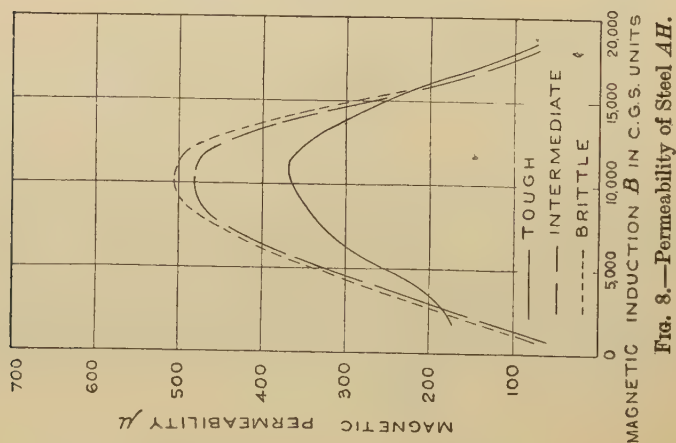


Fig. 8.—Permeability of Steel AH.

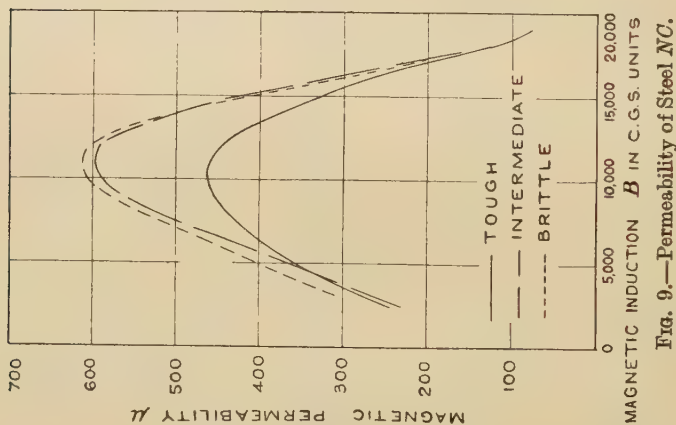


Fig. 9.—Permeability of Steel NC.

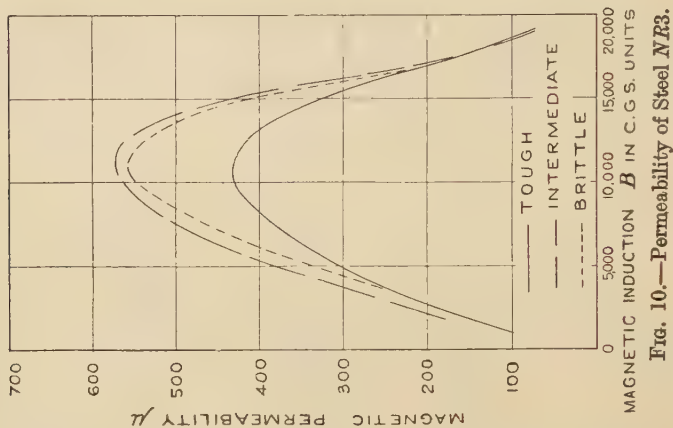


Fig. 10.—Permeability of Steel NR3.

The effect of extra-tempering on the resistivity is shown more fully in connection with the results of the second series of experiments below.

The present experimental results confirm the observation of Kayser,⁽⁵⁾ who noted that in a steel susceptible to brittleness the remanence increased considerably on slow cooling. It has been shown⁽¹⁾ that changes in specific volume and in hardness are accentuated when the tempering temperature is raised, especially near to the Ac_1 range. This, no doubt, applies also to the other physical properties, and appears to account for the absence of detectable changes in resistivity up to 600°C . in the steels examined by Greaves and Jones.⁽²⁾ It is certain that the physical changes in many steels which develop brittleness must be so small as to be very difficult of detection. In the present research steels of a very high susceptibility to brittleness were chosen so that the nature of the physical changes involved could be determined, and a high tempering temperature was used so as to increase as far as possible the magnitude of the changes which would take place on cooling slowly.

SECOND SERIES OF EXPERIMENTS.

From some experiments on steels *AH*, *NC*, and *NR3* previously published⁽¹⁾ (*loc. cit.*, p. 372, third series of experiments), there were available heat-treated Izod specimens which could be used to show the effect of tempering treatments at rising temperatures near to and in the Ac_1 range on the resistivity and specific volume, and also to give a direct correlation of these properties with the Izod values. The long broken ends (about 5 cm. in length) were machined down to $2\frac{1}{2}$ mm. diameter and their resistivities determined. Other parts of the Izod bars were used for specific volume determinations.

The bars had been heat-treated by first oil-quenching from 850°C . and then tempering for two hours at 650°C ., 670°C ., 680°C ., and 690°C . Bars of each steel were obtained in the quenched and slowly cooled conditions (0.3°C . per minute) from each of these temperatures.

The results are shown in Table III. The average Izod and Brinell hardness figures are given for comparison with the resistivity and specific volume values.

TABLE III.—*Resistivity, Specific Volume, Brinell Hardness, and Izod Values.*

Steel.	Tempering Temperature, ° C.	Final Treatment.	Mean Izod Value, Ft.-lb.	Mean Brinell Hardness.	Specific Resistance at 20° C. Microhms.	Decrease in Specific Resistance.	Specific Volume.
AH	650	W.-Q.	58.7	254	32.61	1.12	0.127759
		S.C.	5.5	274	31.49		0.127600
	670	W.-Q.	34.4	297	33.64	1.72	0.127740
		S.C.	7.7	268	31.92		0.127728
	680	W.-Q.	27.2	308	33.82	3.10	0.127768
		S.C.	5.2	260	30.72		0.127750
	690	W.-Q.	8.6	346	38.83	6.24	0.127823
		S.C.	5.2	272	32.59		0.127715
	650	W.-Q.	58.8	260	26.51	0.81	0.127571
		S.C.	5.2	250	25.70		0.127543
NC	670	W.-Q.	70.5	253	26.53	0.64	0.127538
		S.C.	5.0	223	25.89		0.127515
	680	W.-Q.	71.4	237	26.29	0.62	0.127537
		S.C.	5.1	228	25.67		0.127558
	690	W.-Q.	20.0	297	29.19	3.55	0.127612
		S.C.	7.2	228	25.64		0.127536
NR3	650	W.-Q.	69.5	253	24.78	0.72	0.127624
		S.C.	8.3	256	24.06		0.127623
	670	W.-Q.	79.5	238	24.54	0.60	0.127609
		S.C.	15.0	234	23.94		0.127607
	680	W.-Q.	78.7	236	24.70	0.72	0.127605
		S.C.	10.9	237	23.98		0.127592
	690	W.-Q.	68.4	220	25.27	0.97	0.127585
		S.C.	10.2	231	24.30		0.127582

W.-Q. = water-quenched.

S.C. = slowly cooled at the rate of 0.3° C. per minute.

It will be seen that the difference in resistivity between the tough and brittle specimens is greater at the lower temperatures than was the case in the first series of experiments. This is due to the fact that the tempering effects were not equalised, the brittle steel receiving a greater amount of tempering during the slow-cooling treatment. The difference between the resistivity of the tough and brittle specimens is in each case similar until solution in γ -iron at the commencement of the Ac_1 range takes place, when the difference increases sharply, due to the marked effect of the quenched γ areas in raising the resistivity.

The specific volumes of the quenched and the slow-cooled specimens are very similar after treatment at the lower tempering temperatures, the specific volume of the slow-cooled specimens

being in general slightly lower than that of the quenched, due to extra-tempering. Similar remarks apply also to the Brinell hardness results.

It will be noticed that in Tables II. and III. the differences in resistivity and in specific volume given by the different treatments following tempering are of exactly the same order in steel *NC* as in the other steels, but that the magnitude of these properties in steel *NC* is somewhat different in the two series. The different treatments have produced this apparent anomaly in this steel, but at present the reason for it is not clear.

FINAL CONSIDERATION OF RESULTS.

It has been shown that no double effect similar to that obtained in specific volume and in hardness is apparent in the magnetic properties or in the resistivity. The results show that the magnetic properties are modified by cooling the steels slowly from the tempering temperature, and that the magnetic state of the intermediate condition is similar to that of the brittle condition. These facts, together with a consideration of the manner in which the magnetic properties change on slow-cooling, give strong support to the view that temper-brittleness is connected with solution and redeposition of carbide.

The rise in remanence accompanied by a rise in maximum permeability and a small decrease in coercive force and in hysteresis loss are features which would be expected to characterise deposition from solid solution on slow-cooling. The fall in resistivity would similarly be expected.

Thus, at the tempering temperature, some carbide is held in solution in ferrite, and is retained on quenching from that temperature, but separates out on slow-cooling. The double effect in specific volume and in hardness has already been fully discussed ⁽¹⁾ and need not be enlarged upon here.

The explanation of temper-brittleness, therefore, appears to be, briefly, as follows :

When a steel susceptible to temper-brittleness is cooled slowly from a high tempering temperature, a portion of the carbide, which exists at that temperature in solid solution in the ferrite of the steel, separates out, giving definite modifications of magnetic properties and specific resistance. This also results, at moderate cooling rates, in a contraction and softening, as shown by specific

volume and hardness tests. When, however, the rate of cooling is extremely slow, the steel expands and hardens again—relatively to the moderately cooled state—and this is evidently due to the formation of a network of carbide round the grains, producing, by its predominant effect on the coefficient of contraction and its influence in increasing the resistance to penetration, an increase in specific volume and in hardness respectively. Deposition of carbide from solid solution will not in itself induce brittleness in the steel. It is only when the rate of cooling is sufficiently slow to allow of expulsion of the carbide to the grain boundaries that brittleness develops.

Since the foregoing was submitted to the Institute the author has had the opportunity of perusing a recent publication by Honda and Yamada⁽⁶⁾ on the subject of temper-brittleness. These authors, from tests which include comparisons of the magnetisation and the specific resistance of tough and brittle specimens of susceptible steels, arrive at the conclusion that “temper-brittleness is caused by the carbides separated on the grain boundaries along the solubility line below the A_1 point.” They express their substantial agreement with the theory and conclusions put forward by Professor Andrew and the author.⁽¹⁾

This work was carried out by the author at the Royal Technical College, Glasgow, with the aid of a Carnegie Research Fellowship, for the award of which the author is indebted to the Executive Committee of the Carnegie Trust for the Universities of Scotland.

The author desires also to express his thanks to Professor J. H. Andrew, D.Sc., for his continuous interest in this work and for the generous manner in which facilities have always been placed at the author's disposal.

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DISCUSSION.

Dr. W. H. HATFIELD (Member of Council), in opening the discussion, desired to congratulate the author on the excellent experimental data disclosed in his paper. Some of the members had had the pleasure of visiting the Metallurgical Department at the Royal Technical College on the previous day, and they were extremely interested to see such a fine modern installation of all kinds of apparatus, which were available for carrying out investigations of the nature described. He did not think the experimental work and the results obtained could in any sense be questioned as regards fact, and he was of opinion that a material addition had been made to their knowledge of the physical properties of nickel-chromium steels in the two conditions described. From his own point of view he would only be inclined to question a little the author's theoretical deductions. He desired to point out that it was hardly correct to speak of the slowly cooled steels as brittle steels. He suggested that a better term was notch brittleness. If an impact test-piece were made from a slowly cooled nickel-chromium steel and a notch were not made, when the tup came down on the test-piece no signs of brittleness were to be seen; it was very tough indeed. As a matter of fact, there were very important directions in engineering practice in which such alloy steels were used, where it was obviously impossible to submit them to a time-temperature treatment which would in any way coincide with the quick cooling to which the author had submitted his specimens to get the high impact value. Although he had always been intensely interested in the subject, he had not had the pleasure of seeing the carbide which separated out in the manner which the author described. The structures of nickel-chromium steels were so extremely fine that they hardly lent themselves, except under extremely high magnification, to a successful examination such as that to which the author had submitted them.

He desired to ask whether the author suggested that the addition of a little molybdenum to the steels—thus readily introducing a condition in which the slow cooling did not result in notch-brittleness—prevented the separation of the carbide. On the last page of the paper the statement was made: "Deposition of carbide from solid solution will not in itself induce brittleness in the steel. It is only when the rate of cooling is sufficiently slow to allow of expulsion of the carbide to the grain boundaries that brittleness develops." As a matter of fact, if an aero crankshaft, which was only of very small section, were being made, it was well known to all people dealing with such parts that the difference between water-quenching a part like that and cooling it in the air would in some types of nickel-chromium steel lead to an extremely wide variation in the impact value, and he did not think the author

would suggest that a forging of that section should be considered as very slowly cooled within the meaning of that sentence.

Dr. A. BRAMLEY (Loughborough) said he noticed in the tables, particularly in Table III., that the specific volume was given to six places of decimals. He had had very considerable experience in determining the specific volumes of different substances, but he would not like to say that he could determine them correctly to the sixth decimal place. He would like to know how the author obtained his figures. If the sixth decimal figure were not reliable, he suggested it should be omitted. Such figures were a little misleading when they were carried to a decimal place beyond that which had any real meaning.

Mr. J. H. WHITELEY (Saltburn-by-the-Sea) thought that Dr. Dickie had given a very interesting piece of experimental work, which should be of much use to future workers. It was not, however, with that feature of the paper that he desired to deal, but rather with the theory of temper-brittleness which Dr. Dickie endeavoured to uphold. It might be summarised in the following statement, which Dr. Hatfield had already quoted: "It is only when the rate of cooling is sufficiently slow to allow of expulsion of the carbide to the grain boundaries that brittleness develops." Would Dr. Dickie enlarge somewhat upon that view, because he wished to know exactly what was meant by "expulsion of the carbide to the grain boundaries"? Consider a ferrite grain containing carbide particles as sorbite distributed uniformly within it. Supposing the grain were at a temperature just below Ac_1 , at which a certain amount of the carbide might be dissolved in the α -iron. He maintained that, on slowly cooling, that carbide would be deposited, not at the grain boundaries, but on the existing particles within the grain. He thought that conclusion was certain, because the nuclei were already there. If, on the other hand, Dr. Dickie meant that some of the carbide particles themselves were expelled, then there was no need to assume that carbide was soluble. As far as he could make out, however, it was the former process that Dr. Dickie had in mind. By a comparatively slow process of solution and diffusion a certain amount of carbide was deposited at the grain boundary and caused temper-brittleness. If that were really Dr. Dickie's view, he would like him to explain how it was that nuclei at the grain boundary should grow at the expense of particles within the grain. If that explanation were really correct, there appeared no reason why the carbide, in a prolonged slow-cooling, should not move entirely to the boundaries.

Mr. DARTREY LEWIS (London) thought the author had given a very simple and reasonable explanation of temper-brittleness, namely, that at a temperature of about 650°C . the ferrite dissolved a certain amount of carbide. If the cooling from the tempering temperature of 650°C . were rapid, then that carbide was retained in solution in the ferrite, and a tough material resulted; but if the rate of cooling were slow,

then the carbide separated out from solution at the grain boundaries, and produced material which was, to use Dr. Hatfield's term, "notch-brittle." That was a very simple explanation of a difficult problem, and it had been deduced, not from microscopical evidence, although it concerned the microstructure, but from the physical properties of the steel—magnetic properties, density, hardness, and so on. That theory was very interesting, because at a later stage of the meeting Mr. Whiteley would present a paper dealing with a mild plain carbon steel which produced exactly the same microstructure. Mr. Whiteley would prove that a boiler plate steel when heated to 650°C . dissolved a certain amount of carbide in the ferrite; if it were cooled rapidly from that temperature the carbide remained in solution, but if it were cooled more slowly that carbide separated out at the grain boundaries. Mr. Whiteley's slow rate of cooling was about 2000 times as rapid as Dr. Dickie's slow rate of cooling, but that was to be expected because of the influence of the alloying element in reducing the rate of diffusion in the alloy steels. Mr. Whiteley's evidence was based on microscopical examination, and not upon the measurement of any physical properties. The obvious thing seemed to be that Dr. Dickie should test the material with which Mr. Whiteley had been experimenting, to determine, first, whether the material with the carbide at the grain boundaries were brittle, and, secondly, whether Mr. Whiteley's material showed the same changes in physical properties which he had found in nickel-chromium steels. If that were so, then his theory was definitely proved; if it were not so, the theory was not necessarily disproved, but further investigation would be required. If it were proved, a very interesting situation would arise, namely, that temper brittleness was not a property of nickel-chromium steels only, but of all steels, including plain carbon steels, and that the production of temper brittleness was a question of the choice of a suitable rate of cooling. With a plain carbon steel it was a very critical rate of cooling which was not very often produced; but in nickel-chromium steels it so happened that the composition required a rate of cooling such as that which was employed in practice, and that was why temper-brittleness was noticed in them.

Professor J. H. ANDREW (Glasgow) said that since the paper had emanated from his own department he thought it would be rather out of place for him to attempt to discuss it. In the first place, he agreed with everything the author had said in his paper, which was characteristic of all Dr. Dickie's work, in that it represented the highest degree of accuracy. There was only one question he desired to ask, namely, had the author any suitable theoretical explanation at the back of his mind for the extraordinary differences in magnetic properties between the brittle and the non-brittle material?

Dr. H. A. DICKIE, in reply, desired, in the first place, to thank Dr. Hatfield for his very kind remarks. One point which had been raised by several speakers was the separation of carbide at the grain

boundaries. That was a difficult point to discuss, because no conclusive microscopical evidence had so far been put forward. He did not, however, see how the double effect in specific volume and hardness could be explained except by the production of a grain boundary. It was quite probable that it was ultra-microscopic. He did not think a large boundary at all necessary in order to produce the effects found in the specific volume and in the hardness. Also, he thought it unnecessary that all the carbide which was in solid solution at a high temperature should separate at the grain boundaries. It might be that if separation took place at a sufficiently high temperature some of the carbide separated at the boundaries and some of it also probably precipitated on existing carbide within the grains. He had an idea, which was probably not very well founded, that separation at the boundary might be connected with a temperature difference in solubility—that in a steel susceptible to temper-brittleness not only was the solubility of carbide in ferrite fairly large at high tempering temperatures, but that at slightly lower tempering temperatures, say 600°C . down to 550°C ., the solubility decreased very rapidly, and that allowed separation to take place in the steels at what would be called a relatively high temperature. He had examined a number of steels for grain boundaries, but except in one case, a high-phosphorus nickel steel which he could not consider as entirely satisfactory because of the high phosphorus content, he had not observed any. In the case mentioned the boundary was not a continuous film; it was similar to those shown in the micrographs in Mr. Whiteley's paper—a string of globules round the grain boundary. Although there was a succession of globules round the grain boundary, that did not necessarily mean that there was no carbide between the globules. The whole boundary might be influenced by some carbide deposited at all points.

It was quite possible, as Dr. Hatfield had suggested, that the addition of molybdenum might make a difference in the temperature solubility of carbide in α -iron. It might be that the addition of molybdenum lowered the solubility range of the carbide, and that there was not much difference in the solubility of the carbide at, say, 550°C . and 650°C . On the other hand, it might be the case that molybdenum reduced the solubility of the carbide in ferrite so much that no appreciable effects could be produced. He agreed with Dr. Hatfield's remarks on the question of notch brittleness. He did not know that there was any quantitative test that could be carried out on steels without notches, but of course the whole matter referred to effects produced on notched impact pieces.

Dr. Bramley had questioned whether the specific volume determination was accurate to six decimal places. Personally, he had carried out a number of experiments specially designed to show the accuracy of that process, and he concluded from the results that the maximum experimental error was ± 0.000012 . He could hardly reduce it to 0.00001 ; but he found in quite a number of cases that on repeating

a determination he had obtained either the identical figure to the sixth decimal place or to within a few units in the sixth place. He thought, therefore, that it was desirable, when actual repetitions showed such a degree of accuracy, that the exact figures should be quoted; if the figures were given only to the nearest fifth place of decimals there would be a loss in the value of the results.

He was a little surprised to find that Mr. Whiteley disagreed with him on any point, because he (Dr. Dickie) considered that he could not have had better confirmation of his work than that put forward in Mr. Whiteley's paper. Mr. Whiteley was concerned, however, because he thought that, when carbide separated out of solid solution, if there were existing nuclei on which it could be deposited it should deposit on them. Did Mr. Whiteley suggest that there were no nuclei at all in the steels in which he got a separation at the grain boundaries? He did not think any steel could be so pure even within the grain as to contain no nuclei of some kind or other. It was difficult to say exactly what were the conditions for separation at the boundaries, but he thought that if a space lattice could do it—due to the fact that it might be sufficiently expanded—it would expel the carbide to the boundaries; but if it could not, and if the solubility had decreased so that the carbide must separate out, it would separate out within the grain. He did not think that they could go any further than that; possibly, further examination by the X-ray or some new method might prove that point. Mr. Whiteley's paper showed that carbide might separate out in two different forms, either at the grain boundary or throughout the grain. That was exactly the conclusion drawn from his (Dr. Dickie's) work by inference from the physical changes taking place, and he considered that each piece of work was quite a good confirmation of the other. Mr. Whiteley dealt with pure steels, whereas he (Dr. Dickie) had dealt mostly with special steels, sometimes very complex steels, and the effects of the special elements would lead, probably, to different temperatures of separation and perhaps different methods of separation. It might be that in some of the special steels a finer boundary was produced. He also thought that if Mr. Whiteley tested his steels in which he had discovered the carbide grain boundary he would find that they were brittle.

He thought the above remarks in reply to Mr. Whiteley also answered the points raised by Mr. Dartrey Lewis.

He wished to acknowledge the exceedingly kind remarks of Dr. Andrew, who had always been particularly kind to him in every way. In reply to his (Dr. Andrew's) question, the difference in the magnetic properties had really been shown for the first time. It could only be assumed that the changes which had been revealed by his work were produced by the deposition of carbide out of solid solution; he could suggest no other explanation.



THE INFLUENCE OF COLD-ROLLING AND SUBSEQUENT ANNEALING ON THE HARDNESS OF MILD STEEL.¹

BY PROFESSOR C. A. EDWARDS AND PROFESSOR K. KUWADA
(UNIVERSITY COLLEGE, SWANSEA).

MATERIAL AND EXPERIMENTAL PROCEDURE EMPLOYED.

THE object of the experiments described in this paper was to determine the influence of varying degrees of cold work, in the form of cold-rolling, in the direction of increasing the hardness of mild steel, and the temperatures at which this additional hardness is removed. The material used for the experiments was a low-carbon steel sheet 3 ft. by 2 ft., and approximately 1·3 mm. in thickness. The composition of the material was as follows :

							%
Carbon	.	.	.	.	.	.	0·10
Silicon	.	.	.	.	.	.	Trace
Sulphur	.	.	.	.	.	.	0·045
Phosphorus	.	.	.	.	.	.	0·04
Manganese	.	.	.	.	.	.	0·43

The sheet was received from the works in the condition in which it left the hot-rolling mill. It was marked out and cut into experimental pieces 3 in. long by 1 in. wide. The outer edges of the sheet, to a depth of about 3 in., were not used, the object being to use only that portion of the sheet which would give a greater regularity of composition and thickness.

The scale left on the sheet, after hot-rolling, was removed by careful pickling in a dilute solution of sulphuric acid. After this treatment, all the pieces were thoroughly annealed in an electrically heated furnace for two hours at 950° C. To prevent oxidation of the surfaces, during this annealing and subsequent cooling, the specimens were thoroughly wrapped up in thin steel sheets before being introduced into the annealing furnace, and after annealing the packets were allowed to cool in a metal box filled with coal-gas.

¹ Received June 8, 1927.

After numbering the test-pieces, they were rolled to different gauges in a small hand-roller. The rolling operation was carried out in two ways. In one series of tests, which will be called the "once" rolled series, each specimen was rolled in a single pass through the rollers to the desired thickness, the thickness of each test-piece being carefully measured before and after the rolling by means of a micrometer screw gauge. Upwards of five measurements were made for each piece, and the average of these values has been taken as the thickness of the specimen. The identification number of each piece, and the corresponding reduction in its thickness by rolling, are given in columns 1 and 2 of Table I.

TABLE I.—"Once" Rolled Series.

Specimen Number.	Reduction of Thickness. %	After Rolling.	Brinell Hardness Numbers.					
			After Annealing for 30 Minutes at---					
			500° C.	550° C.	600° C.	650° C.	700° C.	750° C.
I. 00	As received	159	147	141	138	115	103	101
I. 0	0.0	111	111	112	110	111	110	110
I. 15	2.3	123	123	123	122	116	115	114
I. 2	4.4	127	131	131	126	121	117	116
I. 3	5.9	134	140	136	130	125	116	114
I. 9	8.5	140	146	142	134	123	107	105
I. 4	11.6	148	107	138	135	124	99.5	102
I. 5	13.0	155	152	150	142	104	105	103
I. 6	16.3	162	161	160	146	104	105	105
I. 12	19.5	161	166	164	144	104	106	106
I. 7	22.3	172	173	166	137	108	106	106
I. 20	25.1	172	179	167	125	109	107	107
I. 21	27.7	177	182	169	118	109	107	107
I. 13	29.0	180	183	169	118	110	107	107
I. 17	31.7	181	188	170	124	113	103	106
I. 22	34.5	183	187	170	112	110	107	107
I. 18	37.1	184	189	171	111	110	108	107
I. 8	39.1	188	191	171	109	111	109	106

In the second series of experiments, which will be called the "twice" rolled series, the procedure was similar to the foregoing, the only real difference being that the ultimate thickness was attained by two passes through the rollers instead of one, the degree of reduction for each pass being approximately the same. The identification numbers, and the percentage reduction of thickness for each pass, are given in columns 1, 2, and 3 of Table II.

TABLE II.—“*Twice*” *Rolled Series*.

Specimen Number.	Reduction of Thickness. %		Brinell Hardness Numbers.						
	First Roll.	Second Roll.	After Rolling.	After Annealing for 30 Minutes at—					
				500° C.	550° C.	600° C.	650° C.	700° C.	750° C.
II. 35	0·0	0·0	111	112	112	112	113	111	110
II. 2	1·6	2·6	127	127	126	119	118	118	114
II. 20	2·6	5·2	134	136	132	125	122	124	118
II. 6	3·7	7·9	141	145	137	132	122	123	117
II. 10	5·3	10·4	148	151	145	138	115	107	104
II. 11	7·6	13·3	152	157	154	142	111	104	104
II. 23	7·3	15·2	154	172	165	142	108	103	104
II. 22	8·9	17·8	152	158	162	132	106	105	105
II. 12	9·5	20·5	161	158	152	144	103	106	106
II. 14	11·4	22·9	167	175	162	125	105	109	108
II. 26	12·9	25·3	168	...	...	...	...	...	...
II. 24	12·9	27·8	171	178	167	118	107	108	108
II. 17	14·8	30·2	173	180	168	116	108	109	106
II. 34	15·9	32·3	174	181	168	115	109	109	106
II. 31	19·5	34·6	178	184	171	115	108	108	107
II. 33	16·8	37·5	179	185	172	114	109	109	107
II. 32	21·6	41·5	183	188	174	113	109	108	105

Since the subsequent method of procedure for each of the two series of experiments was the same, the following observations may be taken as applicable to both. The surfaces of the specimens having been polished with 00 emery-paper, each rolled piece was then carefully and slowly cut up into six pieces measuring about 1 in. by $\frac{3}{8}$ in. Having cut up the long specimens in this way, one small piece was taken from each, which thus gave six series of specimens with a representative piece in each set, corresponding with each degree of rolling. These six series of specimens were carefully wrapped up in thin steel sheets and annealed for thirty minutes at 500° C., 550° C., 600° C., 650° C., 700° C., and 750° C. respectively, and then allowed to cool in an atmosphere of coal-gas after withdrawal from the furnace. The Brinell hardness number of each specimen was again determined; the values obtained are given in Tables I. and II. The Brinell hardness was determined by using a ball 1 mm. in diameter, and a load of 30 kg., which was maintained for thirty seconds. The diameters of the impressions were measured with a micrometer microscope, which gave a magnification of 50. Not less than six Brinell

indentations were made on each specimen, but, in some instances, where variations were observed, an additional six were made, and in all cases the average value of all the impressions was taken. Four distinct readings of the diameters of each impression were taken, and it was found that the variations were within about 3 per cent. (about 0.01 mm. in diameter) with respect to their mean values.

THE DEGREE OF ACCURACY OF THE MEASUREMENTS.

The degree of accuracy of the measurement of the thickness of the test-pieces, after rolling, was not so great as the authors would have liked. There was a tendency for the pieces to curl somewhat during the rolling operation, and on this account the measurements of the reduction of thickness, reported in Tables I. and II., are slightly high ; approximately the same degree of error will, however, apply to each measurement. It was considered inadvisable to straighten the specimens, as this would have given an unknown degree of additional cold work.

It is thought that the degree of accuracy attained in making the measurements of the indentations was high, for the following reasons : A large number of indentations was made on each specimen, and the average value was taken. As the surfaces of the specimens were polished with 00 emery-paper, the impressions were quite sharp, and their edges could be readily focused ; the authors estimate that the measurements of the diameter of an individual impression were correct to within 0.005 mm. All the impressions were situated at least 3 mm. away from the edges of the specimen. The thickness of the thinnest specimen was about ten times the depth of the measurement made on the softest specimen.

Though the specimens showed a tendency to curl in one direction during the rolling operation, the difference in the hardness of the two sides was really not marked. The figures obtained are given in Table III. The hardness of the concave side of every specimen of the "once" rolled series before annealing and after rolling was a little higher, except in one or two instances. With the "twice" rolled series, however, this difference was, to some extent, neutralised, because the second rolling operation was

TABLE III.

"Once" Rolled Series.				"Twice" Rolled Series.			
Specimen Number.	Brinell Hardness Numbers.			Specimen Number.	Brinell Hardness Numbers.		
	Concave Side.	Convex Side.	Mean.		Concave Side.	Convex Side.	Mean.
I. 0	112 ¹	110 ¹	111	II. 35	111 ¹	111 ¹	111
I. 15	124	122	123	II. 2	128	126	127
I. 2	128	126	127	II. 20	134	133	134
I. 3	135	133	134	II. 6	141	141	141
I. 9	142	138	140	II. 10	146	150	148
I. 4	150	146	148	II. 11	151	153	152
I. 5	155 ²	154	155	II. 23	155	153 ²	154
I. 6	163	161	162	II. 22	149 ³	154 ³	152
I. 12	164	158	161	II. 12	163 ²	159 ²	161
I. 7	174	170	172	II. 14	166 ³	168 ²	167
I. 20	171	173	172	II. 26	167	169 ²	168
I. 21	179	175	177	II. 24	168	174	171
I. 13	180	179	180	II. 17	175 ³	171 ²	173
I. 17	182	180	181	II. 34	176 ³	172	174
I. 22	182	183 ²	183	II. 31	180 ³	176 ³	178
I. 18	183	185	184	II. 33	178 ³	180 ²	179
I. 8	191	184	188	II. 32	183 ³	183 ²	183

¹ Plane.² Nearly plane.³ Slightly concave.

always conducted in such a way as to give a tendency to straighten the bend that had been produced during the first rolling.

Some idea of the accuracy of the values given may be obtained by glancing at the figures given in Tables I. and II. for specimens I. 0 and II. 35. It will be noticed that the maximum difference is within ± 2 of the average value of 111. This, it is thought, may be regarded as a fair estimate of the degree of accuracy achieved in making the hardness measurements throughout the whole series of experiments.

DISCUSSION OF THE RESULTS.

The influence of the annealing temperature upon the removal of the extra hardness induced by the varying degrees of cold-rolling can be readily seen by referring to Figs. 1 and 2, where the whole of the data relating to selected specimens for each series of experiments have been plotted against the corresponding annealing temperatures.

Broadly speaking, all the curves can be divided into three more or less distinct ranges of temperature. The first temperature range is 0°C. to 500° or 600°C. , over which there is little or no tendency

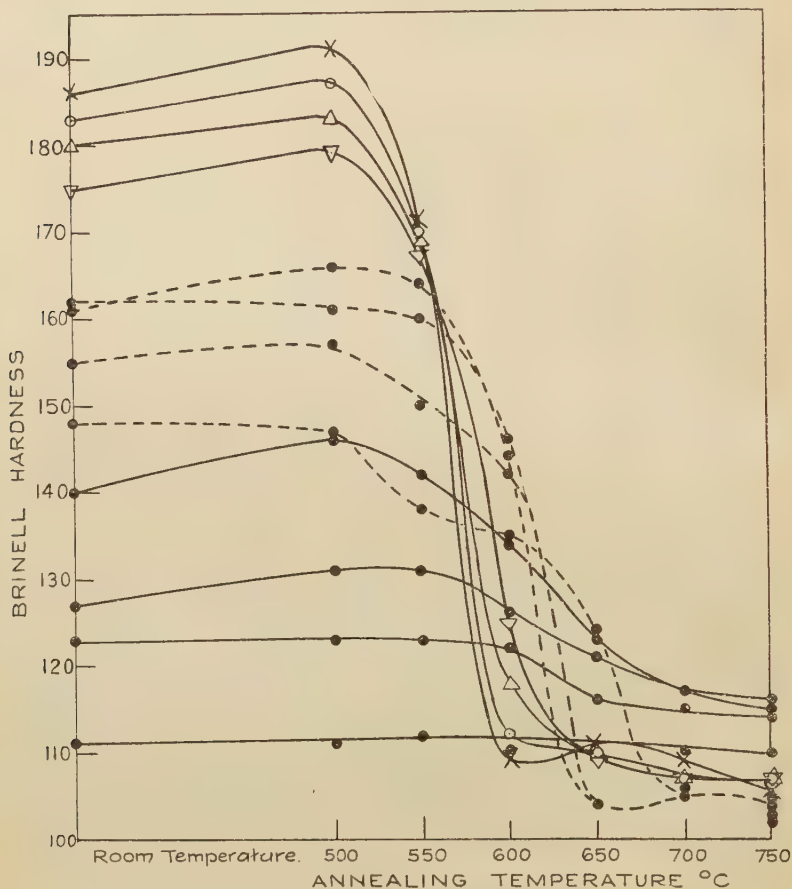


FIG. 1.

for the hardness to decrease; in many instances there is an increase. The upper limit of this range varies from about 500°C. with high degrees of cold work to 600°C. for low degrees of cold work. The second range of temperature is that over which the hardness induced by cold-rolling is comparatively rapidly removed,

namely, from 500° to 600° C. for high degrees of cold work, and from about 600° to 650° C. for low degrees of cold work. The third temperature range is that over which the cold-work hardening has been removed, and little further change takes place on raising

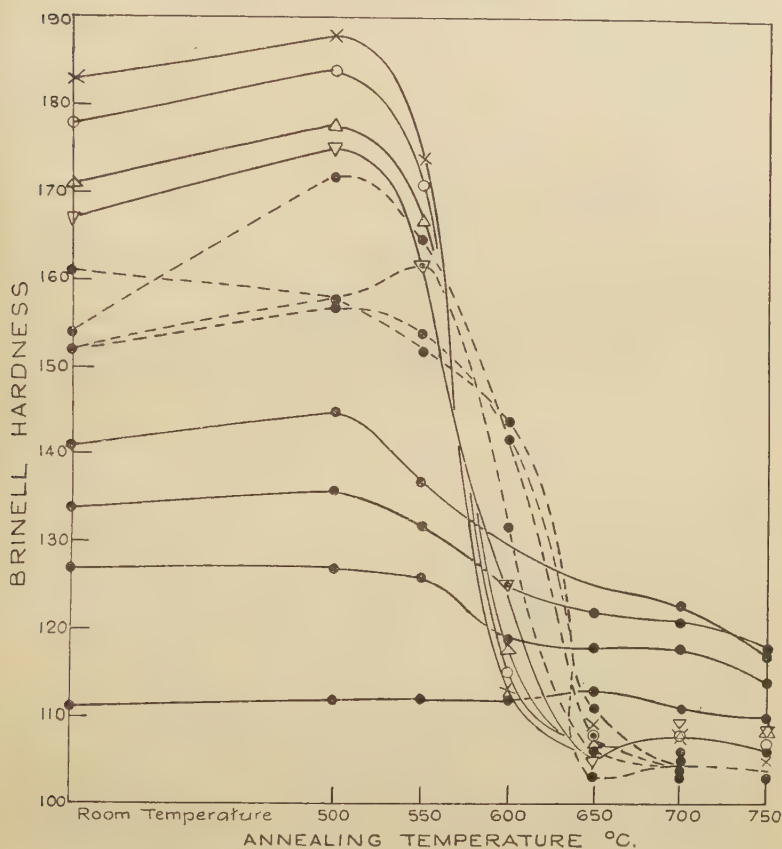


FIG. 2.

the temperature to 750° C. From these curves it can be seen that the slope corresponding with the removal of work-hardening increases and the minima of the curves move to the left with the degree of cold work put on the specimen. The temperature range showing the steepest sections of the curves—that is, corresponding with the quickest rate at which the work-hardening is removed—

lies between 550° and 650° C. when the cold work was not severe, but diminishes to between 550° and 600° C. when the cold work was more pronounced. It will also be noted that the hardness increases in almost all cases when the specimens were annealed at comparatively low temperatures (500° C.).

The above general observations can be stated in more precise terms, as follows :

1. The temperature at which the hardening effects of cold work begin to be removed is lowered as the degree of cold work increases, and the rate at which the hardness is decreased per unit rise of temperature also rapidly increases with the amount of cold work.

2. There is a decided tendency for the hardness of cold-worked steel to increase somewhat by annealing at, say, 500° C.

3. The most effective range of temperature for removing the effects of cold work lies somewhere between 550° and 650° C., but this range becomes rather lower as the degree of cold work becomes greater.

4. It is interesting to note that on annealing at 650° C., or up to 750° C., specimens which have been subjected to intermediate degrees of cold work—that is, between 11.6 and 19.5 per cent. reduction in thickness—the hardness decreases to a value which is clearly below that of the material in the unrolled state, and also below that of the metal in the lightly or very severely cold-rolled conditions, when these have been annealed within the same range of temperature.

Some of the above remarks may be found to be true only in so far as the material under consideration is concerned. The range of temperature, and the amount of cold work referred to in paragraphs 3 and 4 above, may be found to vary with the carbon content and percentage of other elements in the steel, the nature of the cold work, and the duration of the annealing, &c. The above conclusions are, for the most part, in conformity with what was previously known. A much more interesting and instructive conception of the data embodied in Figs. 1 and 2 can be obtained by plotting the hardness values, after annealing at the temperatures stated, and the degree of cold work to which the specimens have been subjected as co-ordinates. This has been done for each particular temperature, and the curves for each series of rolling

experiments are shown in Figs. 3 and 4. This is a more convenient method for examining the results, especially when considering the detailed explanation of the relationship between the

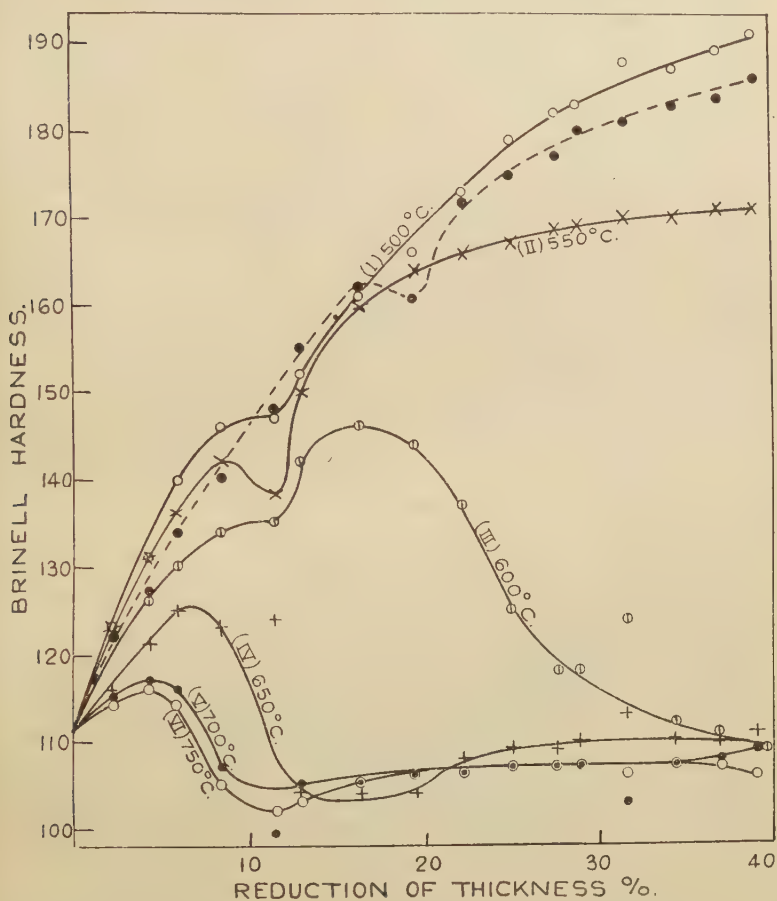


FIG. 3.

degree of cold work and the influence of annealing temperatures on the hardness. Fig. 3 corresponds with the "once" and Fig. 4 with the "twice" rolled series; in both instances the dotted lines represent the effects of varying degrees of rolling on the hardness of specimens which had not been subsequently

annealed. Curves I. to VI. show the data obtained with similar specimens after they had been annealed at temperatures of 500°C ., 550°C ., 600°C ., 650°C ., 700°C ., and 750°C . respectively.

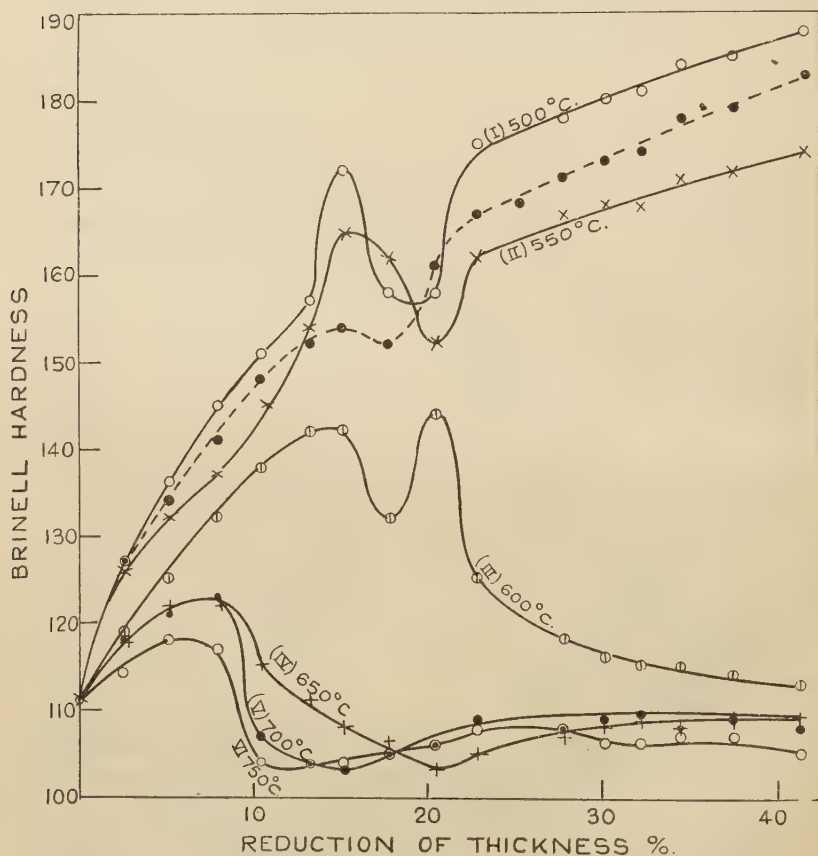


FIG. 4.

In view of the fact that the general characteristics of the curves in Figs. 3 and 4 are so similar, it is not necessary to give a separate detailed description of each set. It will be observed, on referring to the dotted curves in these figures, that there is a small break or relative minimum point in each case, which occurs a little below 20 per cent. reduction in thickness. Though the hardness values of these points do not differ very substantially from those on either

side, and may be considered to be very near the limits of experimental error, the curves are drawn to show the discontinuity. This has been done, not only because similar breaks have been found with the "once" and "twice" rolled series, but also because they appear to have a bearing on similar discontinuities that occur in some of the curves after annealing.

On examining the shapes of the six full-line curves in Figs. 3 and 4, it will be noticed that these can be readily classified into three types, namely, those which have: (a) one maximum and one minimum, with the ends of the curves higher than the beginnings—for example, curves I. and II. in each set of results; (b) one minimum and two maxima, such as curve III., Figs. 3 and 4; and (c) one maximum and one rather drawn-out minimum, and both ends showing approximately the same hardness. From these curves it will be seen that the positions of the minima are between 10 and 17 per cent. reduction in Fig. 3, and 10 and 23 per cent. reduction in Fig. 4, differing according to the annealing temperature on the one hand, and whether "once" or "twice" rolled on the other.

MICROSTRUCTURES.

For the examination of the microstructures of the specimens complete sections were cut, and mounted in such a way as to permit of the whole of the section being examined parallel with the direction of rolling. They were polished in the usual manner, and etched in an alcoholic solution of picric acid. A large number of samples, representing typical examples of various types, and the more salient features of the curves shown in Figs. 3 and 4, were examined, and a few micrographs of these are reproduced in Figs. 6 to 15 (Plates XIV. to XV.). The magnification in each case is 150 diameters.

A typical structure of the steel in the annealed state, before rolling, is illustrated in Fig. 6, and another sample of the same material, rolled to the extent of 17.8 per cent. reduction of thickness, but not annealed, is shown in Fig. 7. The latter may be taken as showing the typical distortion of the structure as the result of rolling; but other structures, which will be referred to later, representing a higher degree of distortion, are illustrated,

although they have been taken from specimens which had been annealed at temperatures which were too low to permit of the complete removal of the rolling stresses. At this stage, the authors would like to state that they experienced some difficulty in making really satisfactory comparisons of the grain-sizes of various specimens, because there was a decided tendency for the crystals at and near the edges of the specimens to be rather smaller than those in the centre. In view of this, all photographs were taken as near as possible to the middle of each specimen.

Figs. 8 and 9 represent the structures of specimens which had been cold-rolled to the extent of 11.6 and 16.3 per cent. and annealed at 700° C. and 650° C. respectively. These show unmistakable signs of grain growth, and may be taken as typical of those parts of curves IV., V., and VI., Figs. 3 and 4, which lie between 8 to 20 per cent. reduction in thickness and show a lower hardness value than the original steel in the annealed condition.

Figs. 10 and 11 show the structures of specimens which had been rolled to 25 and 39 per cent. reduction respectively, and annealed at 500° C. In both these specimens there was a slight increase in the hardness after the above-mentioned heat treatment. The distorted structure, resulting from rolling, is very clearly evident, and there are no indications of any recrystallisation. The increase in the hardness of these and other specimens, caused by heating to 500° C., is, no doubt, caused by what may be described as the conversion of some intercrystalline and interatomic elastic stresses into permanent strain. The structures of specimens subjected to the same kind of cold work as those just referred to, but after annealing at 600° C., are illustrated in Figs. 12 and 13. In the latter it will be observed that complete recrystallisation has taken place and has resulted in the production of very small crystals, whilst in the former the ferrite crystals are elongated and irregular, though, of course, recrystallisation has already set in to a marked degree. A comparison of these two micrographs shows very clearly how the greater amount of cold work facilitates recrystallisation. Figs. 14 and 15 represent the structures of specimens which have been cold-rolled to the same extent as those just mentioned, and then annealed at 650° C. Complete recrystallisation has taken place in each instance, though it will be observed that the number of centres

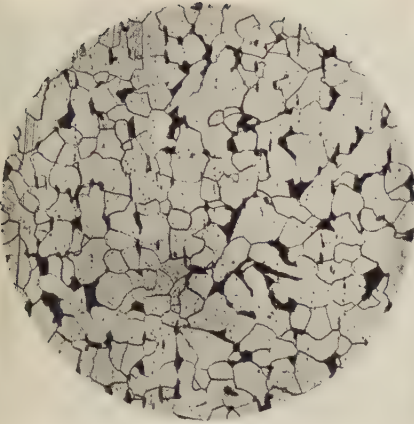


FIG. 6.—Structure of original metal in the annealed state. $\times 150$.

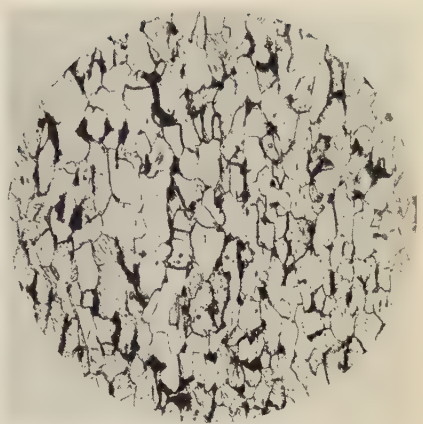


FIG. 7.—Cold-rolled 17.8 per cent. Unannealed. $\times 150$.

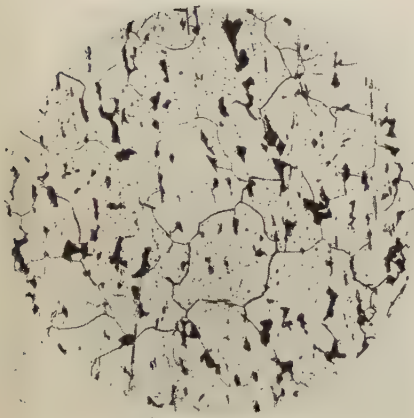


FIG. 8.—Cold-rolled 11.6 per cent. Annealed at 700°C . $\times 150$.



FIG. 9.—Cold-rolled 16.3 per cent. Annealed at 650°C . $\times 150$.

(Reduced in reproduction to four-fifths.)

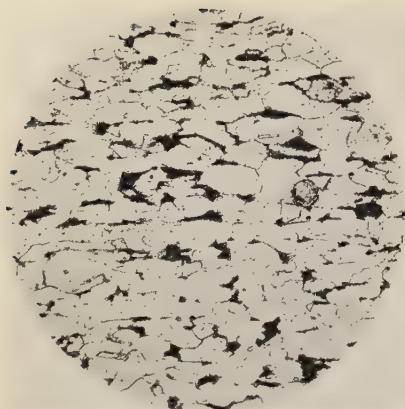


FIG. 10.—Cold-rolled 25.1 per cent.
Annealed at 500° C. $\times 150$.

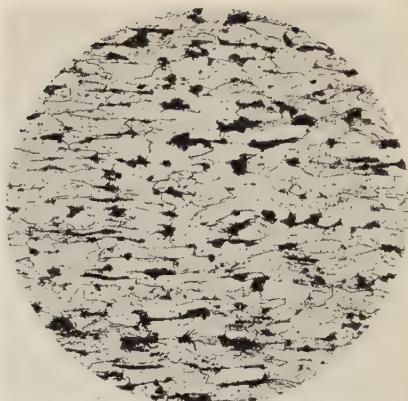


FIG. 11.—Cold-rolled 39.1 per cent.
Annealed at 500° C. $\times 150$.

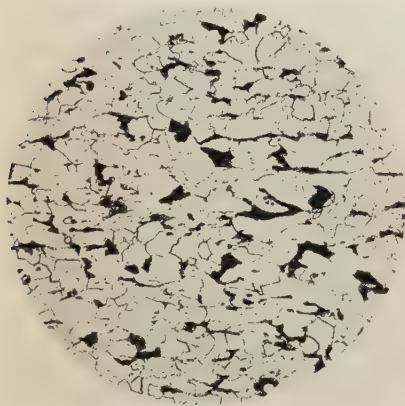


FIG. 12.—Cold-rolled 25.1 per cent.
Annealed at 600° C. $\times 150$.

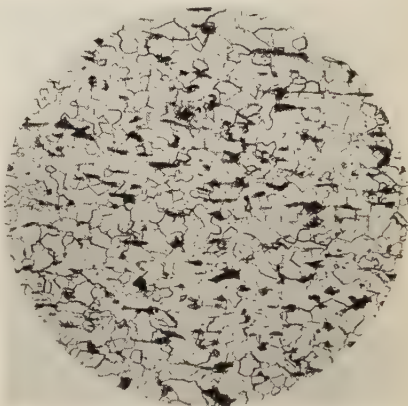


FIG. 13.—Cold-rolled 39.1 per cent.
Annealed at 600° C. $\times 150$.



FIG. 14.—Cold-rolled 25.1 per cent.
Annealed at 650° C. $\times 150$.

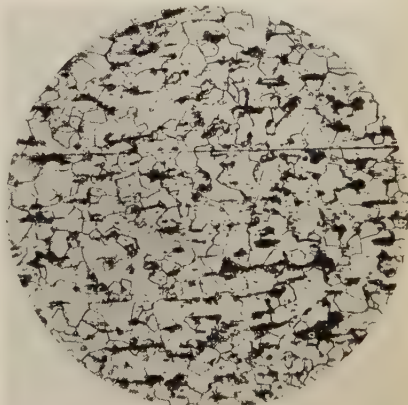


FIG. 15.—Cold-rolled 39.1 per cent.
Annealed at 650° C. $\times 150$.

(Reduced in reproduction to four-fifths.)

from which this has commenced was greater in that specimen which was subjected to a large amount of cold work.

Before attempting to advance possible explanations of the inner changes that might take place to account for the varying effects of annealing temperature on specimens which had been subjected to different degrees of cold work, it will be useful to give a brief review of some previously known facts which have a bearing on these phenomena. In the work by Carpenter and Elam,¹ it was shown that a critical degree of strain was required in order to produce single crystals. When the straining was less than this critical amount it was removed, on annealing, without crystal growth taking place. With greater straining, single crystals were not produced on annealing, and the crystal size obtained became less as the amount of strain was increased. Working along similar lines, but with decarburised mild steel, Pfeil and one of the present authors² found that the critical strain required to produce very large crystal growth on subsequent annealing varied with the initial grain-size of the material used. This variation was in the direction of a greater strain being needed as the grain-size increased. With very large crystals, sufficient strain to cause growth could not be applied, owing to the fact that the material at and near the crystal boundaries became so severely strained that complete recrystallisation occurred in those zones. It was also found that the additional hardening which was produced by cold-working very large crystals, even to the extent of 25 per cent. elongation, could be completely removed by annealing without the material undergoing recrystallisation. From these facts, and from additional evidence which has been brought to light by other investigators, it would seem that the influence of varying degrees of cold work upon the character of the inner changes that occur in the metal can be conveniently divided into three ranges :

1. A low degree of deformation, which causes such comparatively small interatomic disturbances of the space lattice that it can be removed by annealing at an appropriate temperature

¹ H. C. H. Carpenter and C. F. Elam, "The Growth of Large Crystals of Aluminium by Straining and Subsequent Annealing," *Proceedings of the Royal Society*, 1921, (A), vol. c. p. 338.

² C. A. Edwards and L. B. Pfeil, *Journal of the Iron and Steel Institute*, 1925, No. II. p. 79.

without causing grain growth or recrystallisation. That is to say, the atoms can swing back into the positions they occupied before straining, and the original orientation of each individual crystal can be resumed, though the shape of each crystal will be somewhat different from what it was before straining.

2. A higher degree of deformation, which is accompanied by more severe interatomic disturbances (caused by interference with true slip owing to the boundary effects of contiguous crystals), can give rise to what may be conveniently called a rotation of the crystallographic axes, which is the initial stage in the formation of exceptionally large crystals that are developed on subsequently annealing. This critical amount of deformation causes such a high degree of axial alignment of the atoms, due to rotation, that, on annealing, it is more easy for the atoms to form a single crystal than to revert to their original orientations.

3. With still greater degrees of deformation, the disturbance of the space lattice becomes so great that the axial alignment, referred to in paragraph 2, is broken down and, on annealing, it is easier for the atoms to recrystallise and thus form quite new crystals. The degree to which this recrystallisation sets in, or the number of points at which it commences, increases with the extent of the original deformation.

It should be clearly understood that the above remarks on the influence of varying degrees of strain and subsequent annealing are only strictly applicable, as they stand, to the conditions which govern the growth of phenomenally large crystals. In endeavouring to make use of the underlying principles which they involve for the purpose of extending them to the present investigation, other disturbing factors would have to be taken into account. For example, in the present work, the authors have not been concerned with the growth of extraordinary large crystals, but only with that relatively small degree of crystal growth which may have an effect upon the Brinell hardness value. Further, no attempt has been made, up to the present, to determine the effect of the period of annealing upon the crystal size on the one hand, or the hardness on the other.

In the light of the foregoing observations and the experimental evidence embodied in the present paper, the authors feel that the conclusions set out in the next section may be drawn.

CONCLUSIONS.

Let the line *ABC* of Fig. 5 represent the Brinell hardness values of mild steel specimens which have been cold-worked to varying degrees between 0 per cent. up to about 40 per cent. reduction of thickness. This curve is similar to those corresponding with the cold-rolled unannealed specimens in Figs. 3 and 4, with the exception that it has been drawn perfectly smooth, and

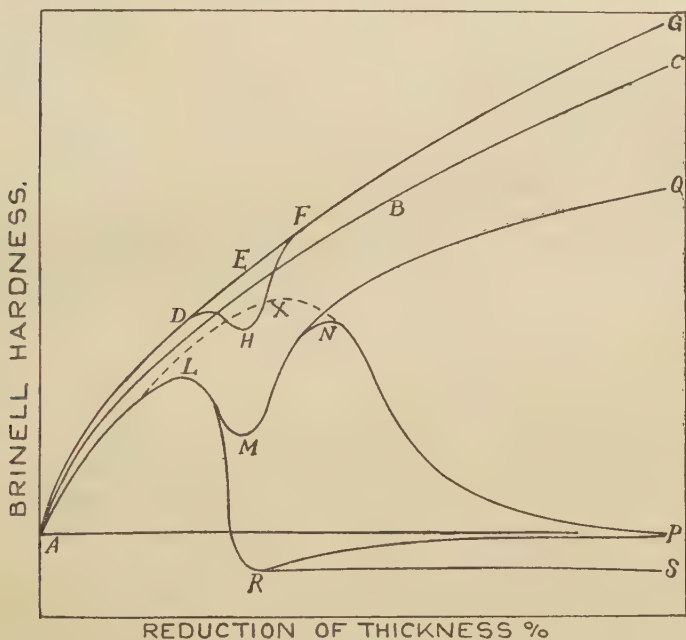


Fig. 5.

shows no break at approximately 20 per cent. reduction. When such specimens are annealed at temperatures above, say, $600^{\circ}\text{C}.$, but below some upper limit which may for the present purpose be defined as $750^{\circ}\text{C}.$, crystal growth occurs in some of them which have been cold-worked within certain limiting degrees, whereas greater degrees of cold work cause recrystallisation to set in. Both these changes cause a decrease in the hardness of the metal, and a hardness curve of the type *ALRP* is obtained. The height

of the maximum L on that curve decreases, and the position of the minimum R moves more to the left, as the annealing temperature is raised. This means that, within the range covered by ALR , the smaller the amount of cold work the higher is the temperature required to cause its removal; and, further, the higher the annealing temperature the smaller is the amount of cold work at which crystal growth is produced. The section of the curve RP represents the influence of still greater degrees of cold work in causing more and more recrystallisation of the metal to take place, and the rise in the hardness from R to P is due to the decrease in the size of crystals. If it were not for this the curve would follow the line RS . When a somewhat lower annealing temperature than those just referred to is used, say about 600°C ., the character of the curve obtained is represented by $ALMNP$. The minimum at M is clearly due to grain growth having taken place. The slope of the curve NP is caused by the greater degrees of cold work increasing the facility with which recrystallisation can take place at this intermediate annealing temperature. The peculiar shape of the curves shown in Figs. 3 and 4, which are similar to $ALMNP$ (Fig. 5), is due to the overlapping of the tendency for grain growth to occur with certain critical strains on the one hand, and to the increasing tendency for recrystallisation to take place with the degree of cold work from N to P on the other. In other words, if no critical strain grain growth took place on annealing at intermediate temperatures of about 600°C ., it may be assumed that the hardness curve would take the form of the curve $ALXNP$ (Fig. 5).

Turning now to a consideration of what happens at the low annealing temperature of about 500°C ., if the temperature is just high enough to change some of the internal elastic stresses into strains, but not enough to allow of recrystallisation, then the hardness will tend to become a little higher than before the heat treatment, and thus follow the line $ADEFG$. If, however, the annealing temperature is a little higher than the hypothetical case just considered, then crystal growth, or at least the first step in that direction, will take place within a limited range of cold work, and the hardness curve will, no doubt, take the form $ADHFG$. This type is realised to some extent in curve I., Fig. 3, and also to a limited extent in curve II. In the latter case, however, it will

be observed that the hardness obtained after heat treatment is, generally speaking, somewhat lower than that before heat treatment.

In all probability all the maxima and minima on these curves, after annealing, will vary to some extent with the annealing temperature, with the initial grain-size (before rolling), and, perhaps, with the duration of annealing.

When examined in the light of the above observations, it would seem that the discontinuities which occur at about $17\frac{1}{2}$ per cent. and 20 per cent. reduction of thickness in the unannealed curves (Figs. 3 and 4) are in some way associated with the minima which occur as a result of grain growth, and may, indeed, be a reflection of an effort on the part of the material to undergo this change spontaneously. In this connection, it is rather interesting to remember that Alkins¹ found a similar discontinuity in the physical properties of copper which had been subjected to progressively increasing amounts of cold work.

¹ W. E. Alkins, *Journal of the Institute of Metals*, 1918, No. 2, p. 33; 1920, No. 1, p. 381.

CORRESPONDENCE.

Mr. A. ALLISON (Sheffield) wrote that the authors were to be congratulated on their very careful work, particularly in recording average figures of measurements.

There appeared to be five properties to be recorded and correlated in annealed dead soft steel—namely, hardness, tensile strength, grain-size, ability to undergo pressing or Erichsen tests, and magnetic properties. In the present paper the authors dealt with the hardness, and to some extent with grain-size, while in the paper presented in May,¹ Professor Edwards and another worker dealt with drawing properties and tensile strength, so that the data supplied ran in parallel.

The central features appeared to rest in the four conclusions on p. 252. With regard to conclusion No. 2, that the hardness of cold-worked steel had a tendency to increase on annealing at 500° C., some of the experiments recorded in the earlier paper showed that the Erichsen values dropped upon annealing at 450° C., and the upward curve was not resumed until an annealing temperature of 550° C. was reached, so that hardness and Erichsen tests were experimentally correlated. In observation No. 4 it was pointed out that on annealing at 650° C. and upwards, specimens cold-worked to the extent of 11·6 to 19·5 per cent. gave a minimum hardness. Previous investigators had found that this temperature and degree of deformation coincided with maximum grain growth, and the micrographs Figs. 8 and 9 appeared to confirm that finding. It was somewhat astonishing that when Dr. Edwards was endeavouring to produce large crystals, as recorded in his paper in 1924,² he obtained the best large crystals by annealing after a tensile deformation of 2·75 to 3·5 per cent. It was true that in that research he was dealing with decarbonised metal, but the difference in these critical percentages of deformation was such, that he would like to ask Dr. Edwards for any further explanation he could suggest.

He (Mr. Allison) quite agreed with the explanation on pp. 257–258 that hardness could be removed by annealing, without causing grain-growth or recrystallisation, but the next paragraph, suggesting that large crystals resulting from annealing after a medium degree of deformation were produced by the rotation of crystal axes, provoked an alternative theory. It was generally agreed that large crystals originated in the recrystallisation of slip-band material, and that the small new crystals behaved as nuclei, having an extraordinary aptitude for

¹ C. A. Edwards and J. C. Jones, "The Influence of Annealing Temperature on the Properties of Mild Steel Sheets," *Journal of the Iron and Steel Institute*, 1927, No. I. p. 523.

² C. A. Edwards and L. B. Pfeil, "The Production of Large Crystals by Annealing Strained Iron," *Journal of the Iron and Steel Institute*, 1924, No. I. p. 129.

feeding on the adjacent material with a disturbed space lattice, and thus became large crystals. That only took place, however, while the whole system was relatively plastic, because if the annealing were too short or the temperature slightly low, reannealing did not cause a resumption of the grain growth.

The above suggestion led to an alternative theory in lieu of paragraph 3, namely, that with a greater degree of deformation the number of nuclei was greater, and consequently the relatively large number of new crystal units in competition for the available material resulted in the production of a large number of medium-sized crystals.

He (Mr. Allison) had found in his own work that the grain-size in thin strip steel was to some extent relative to the gauge of the material, and the authors would no doubt agree that the data recorded in the paper were relative only to the somewhat thin gauges of sheet employed for the experiments.

Dr. EDWARDS, in reply, expressed his appreciation of the interesting communication contributed by Mr. Allinson. He was glad to observe that Mr. Allinson agreed with the general conclusions which the authors had arrived at as a result of their work.

With regard to the question raised as to the remarkable difference in the behaviour of decarburised mild steel in respect to the growth of large crystals and that of the material containing about 0.1 per cent. of carbon, such as was used in the present investigation, he (Dr. Edwards) could only suggest, at the present stage, that it was due to the presence of comparatively small quantities of carbon, being dissolved in the ferrite in the case of the undecarburised material. There was, however, another possible disturbing factor, namely, possible variations in the original size of the ferrite crystals when carbon was present. That was a matter which was receiving further consideration, and he (Dr. Edwards) hoped soon to be in a position to throw further light on that question.

Dr. Edwards was pleased to receive Mr. Allinson's alternative suggestion concerning the cause of grain-growth in mild steel, and would bear it in mind in his future work.

THE WORK-HARDENING OF STEEL BY ABRASION, WITH AN APPENDIX ON THE "CLOUDBURST" TEST AND SUPERHARDENING.¹

BY EDWARD G. HERBERT, B.Sc., M.I.MECH.E. (MANCHESTER).

INTRODUCTION.

THE present work describes an investigation into the hardness induced by severe abrasion in locomotive tyres and rails, and in hardened steel gears and cams from motor-cars. The hardness induced by wear is compared with the "maximum induced hardness" measured by a recently developed test made with the pendulum hardness tester.

A somewhat similar comparison between the hardness induced by lathe tools in the process of cutting certain steels, and the hardness induced by the pendulum in the same steels, has been previously described by the author.²

I. THE MEASUREMENT OF WORK-HARDENING CAPACITY.

The Time Test.—For the purpose of measuring the original hardness of the subjects investigated and for measuring the hardness of the worn surfaces, the time test of the pendulum hardness tester was used. The pendulum and the time test have been described by Benedicks and Christiansen.³ Briefly, the pendulum, weighing 4 kg., is placed on the specimen, a hard sphere 1 mm. in diam. acting as pivot, and is caused to oscillate through a small arc. The time period of oscillation, taken with a stop-watch, is a measure of the size of the indentation, and thus of the hardness of the specimen.

The Time-Work-Hardening Test.—The work-hardening

¹ Received March 23, 1927.

² "The Work-Hardening Properties of Metals: their Relation to Metal-Cutting Operations and Cutting Temperatures," *American Society of Mechanical Engineers*, Dec. 1926; *Engineer*, 1927, vol. cxliii., Feb. 4, p. 138; Feb. 11, p. 156; Feb. 18, p. 180.

³ *Journal of the Iron and Steel Institute*, 1924, No. II. p. 219.

capacity of the metal is measured by a succession of time tests on the same spot, each test being followed by a process of rolling effected by tilting the pendulum to the right, to the left, and back to the vertical position. This process rolls out the original circular impression into an elongated form (Fig. 10, Plate XVII.) and work-hardens the metal, the succeeding time test, made in the centre of the rolled surface, serving to measure the hardness thus induced. There is thus obtained a series of time-hardness numbers, of which the first gives the original hardness, the second the hardness induced by two passes of the ball, the third the hardness due to four passes, and so forth. The hardness always rises to a maximum—"the maximum induced hardness"—and then declines with further rolling.

Thus the time-work-hardening test measures two distinct properties of the metal, its "original hardness" and its "maximum induced hardness." The former corresponds with the hardness measured by the Brinell and other hardness tests. The latter depends on and measures the capacity of the metal for hardening by cold-work.

Time-hardness numbers are convertible into approximate Brinell numbers, and for the convenience of those more familiar with the Brinell scale, the equivalent Brinell numbers are given throughout the paper.

The conversion is effected by the following formulæ which apply to steel:

$$\begin{aligned} B &= 0.36T^2, \text{ when } T \text{ is 28 or less;} \\ B &= 10T, \text{ when } T \text{ is above 28;} \\ B &= 13.5D \text{ on hard steel;} \end{aligned}$$

where B is the Brinell number, T the time-hardness number obtained with the 1-mm. steel ball in the pendulum, and D the time-hardness number given by the pendulum and 1-mm. diamond sphere.

The manner in which the induced hardness rises to a maximum and declines can be seen from the figures in Table I., which apply to a number of typical metals. In Table II. the various steels have been extracted from Table I. and placed in the order of their original hardness, the maximum induced hardness being given together with the approximate Brinell hardness corresponding to each.

TABLE I.—*The “Induced Hardness” of Some Typical Metals.*

Passes of Ball.	0.	2.	4.	6.	8.	10.	12.	14.	16.	18.	20.
Mild steel . . .	<u>21.2</u>	30.4	30.4	30.7	<u>31.5</u>	30.4	...	...	...	...	...
Manganese steel .	<u>21.0</u>	45.5	52.4	54.0	<u>56.2</u>	<u>57.2</u>	44.6	...	...	...	...
Stainless steel A .	<u>18.0</u>	38.2	41.9	43.1	<u>44.0</u>	43.8	...	...	...	...	...
Stainless steel B .	<u>19.7</u>	41.2	45.4	47.3	<u>48.2</u>	49.8	50.3	51.5	52.3	<u>52.9</u>	49.6
Stainless steel C .	<u>27.5</u>	35.6	35.8	36.3	<u>36.5</u>	36.2	...	...	...	...	...
Stainless iron . .	<u>19.6</u>	<u>32.5</u>	31.6	30.4	...	...	...	...	...	...	...
Hard carbon steel ¹	<u>55.4</u>	69.0	70.7	70.8	<u>71.4</u>	70.0	...	...	...	...	...
Hard nickel steel ¹	<u>54.5</u>	81.0	85.2	<u>88.7</u>	87.3	...	...	...	...	...	...
Cast iron . . .	<u>30.0</u>	36.4	37.5	38.2	40.6	<u>40.8</u>	40.2	...	...	...	...
Brass . . .	<u>19.4</u>	<u>32.0</u>	32.0	31.8	...	...	...	...	...	...	...
Copper ² . . .	<u>6.8</u>	17.5	19.8	20.8	21.5	23.5	23.5	23.7	<u>24.4</u>	24.2	...
Aluminium ² . .	<u>5.5</u>	9.8	10.1	10.3	<u>10.7</u>	10.6	...	...	...	...	...

¹ Tested with diamond 1 mm. in diameter.² Tested with 3-mm. steel ball, etched to prevent slip.TABLE II.—*Hardness and “Maximum Induced Hardness” of Various Steels.*

	Original Hardness.		Maximum Induced Hardness.	
	Time.	Brinell.	Time.	Brinell.
Stainless steel A . . .	18.0	116	44.0	440
Stainless iron . . .	19.6	138	32.5	325
Stainless steel B . . .	19.7	140	52.9	529
Manganese steel . . .	21.0	158	57.2	572
Mild steel . . .	21.2	162	31.5	315
Stainless steel C . . .	27.5	270	36.5	365
Hard nickel steel . . .	54.5	735	88.7	1197
Hard carbon steel . . .	55.4	749	71.4	964

Among the unhardened steels, the highest induced hardness was given by manganese steel which was originally very soft, whereas the mild steel which was originally harder had a much lower induced hardness. The hardest stainless steel (C) showed only a moderate increase of hardness, stainless steels A and B, which were originally much softer than C, becoming considerably harder as the result of rolling.

The two hardened steels were tested with the diamond in order to eliminate any effects due to superhardening of the ball, and the Brinell conversion factor 13·5 was used. The hard nickel steel, though originally less hard than the hard carbon steel, showed a much greater increase of hardness. Its maximum induced hardness was equivalent to nearly 1200 Brinell, a degree of hardness which has rarely been exceeded in steel.

The fact that articles of very hard steel can be superhardened by working was discovered by means of the pendulum work-hardening tests, and independently by Hultgren, who turned it to practical account in the superhardening of steel balls. It is perhaps not sufficiently recognised that this effect normally occurs when hard steel articles are subjected to severe abrasion. This subject is dealt with in the next section.

The process of work-hardening in unhardened metals has been studied in some detail, and is known to be accompanied by slipping of the metal along definite crystallographic planes. Whether the superhardening which takes place in hardened steels is strictly analogous is not known. Recent experiments suggest that it may be accompanied by a consolidation of the metal—an actual decrease of volume—but this is not yet certain.

As it is proposed to consider the process only in relation to its practical effects, it will suffice to say here that the superhardening of hard steel is as considerable in amount, as important in its practical results, and as easily measured as the work-hardening of the softer metals.

II. WORK-HARDENING OF METALS IN SERVICE.

A. *Work-Hardening of Railway Tyres and Rails.*—An investigation was made into the degree of work-hardening that had occurred in actual service in a series of locomotive tyres and rails which had been in long use, and had been discarded as worn out. Fig. 1 shows a section through a worn locomotive tyre which was tested for hardness with the pendulum time test in the positions shown. The hardness of the body of the tyre was 26·4 (251 Brinell), and 1·6 mm. from the surface 31·6 (316 Brinell). The highest hardness on the actual worn surface was 34·2 (342 Brinell).

A time-work-hardening test was made on a part of the section which had not been hardened by service conditions in the position

indicated by the elliptical impression (Fig. 1) with the following results :

<i>Passes of Ball:</i>	0.	2.	4.	6.
Time hardness .	<u>26.2</u>	31.7	<u>32.0</u>	32.0

The original hardness 26.2 increased to a maximum 32.0 as a result of rolling four times. It appears from Fig. 1 that the

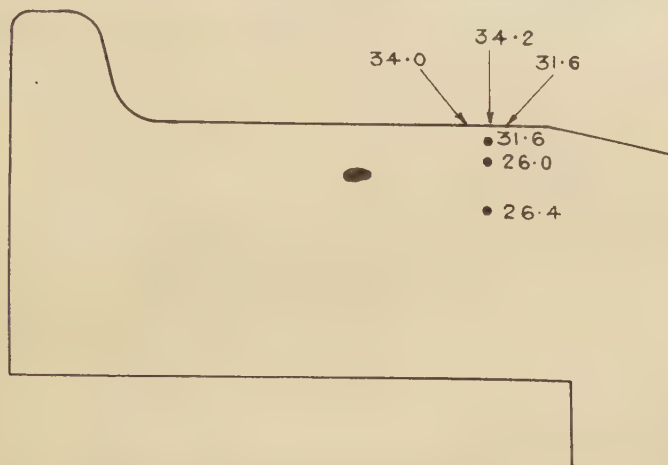


FIG. 1.—Section of Locomotive Tyre tested for Hardness and Work-Hardening.

hardness induced by wear was rather higher than the maximum that could be induced by rolling.

In Fig. 2 is another worn tyre on which two series of time tests were made. In each case there was evidence of work-hardening, extending 3 mm. below the surface, but the hardness on the actual surface was much higher, rising at one point to 64.8 (648 Brinell).

Time-work-hardening tests in the two regions gave the following results :

<i>Passes of Ball:</i>	0.	2.	4.	6.	8.
Time hardness .	<u>25.8</u>	33.6	34.0	<u>34.4</u>	33.6
	<u>28.6</u>	35.6	<u>36.2</u>	36.0	...

In this case the maximum hardness on the surface (64.8) was very much higher than the maximum hardness induced by the pendulum. To account for this it must be remembered that a

locomotive tyre in service is subjected not only to work-hardening by abrasion and shock, but also to the action of sand used in braking, and to very high temperatures generated by friction.

It seems safe to infer that the hardness induced by wear in the surface of a locomotive tyre is not less but generally greater, and occasionally much greater, than the maximum hardness that can be induced by the pendulum.

The original hardness of the tyre has no importance in relation to resistance to abrasion, since steel possessing this hardness is not in contact with the rails after the tyre has been in use.

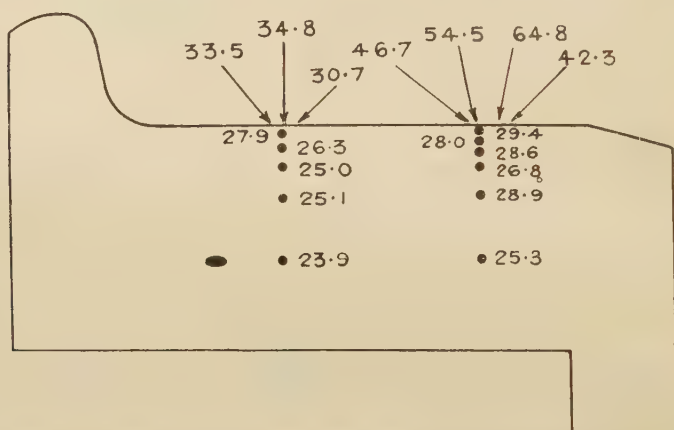


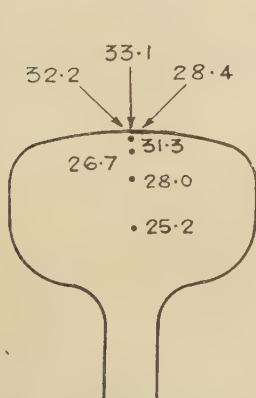
FIG. 2.—Section of Locomotive Tyre tested for Hardness and Work-Hardening.

It will be observed that the tyre which gave the highest induced hardness in the test (Fig. 2) possessed the highest hardness induced in service, and this is to be expected apart from the extra hardening due to sand and heat.

A similar investigation was made on a series of worn-out rails, and typical results are given in Figs. 3 and 4. In each case the result of the pendulum time-work-hardening test is given below the figure. The rail, Fig. 3, gave the highest maximum induced hardness 35.5 (355 Brinell). In each case a considerable degree of hardness was induced by abrasion in service, this induced hardness being greatest on the surface and extending some depth into the body of the rail, but in neither case was the hardness induced by service equal to the maximum induced by the pendulum.

It is evident, however, that the original hardness of the rail can have no importance in relation to resistance to wear, since steel possessing this hardness is not in contact with the wheels of the rolling stock.

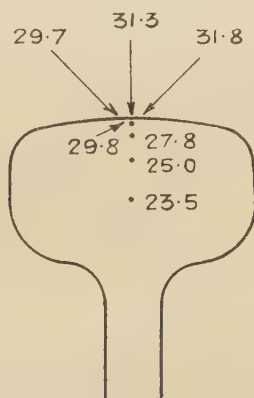
Although the hardness induced in the rails investigated was not equal to the maximum of which the steel was capable, it is probable that a different result would be obtained from the end of a rail, as this portion is subjected to severe shock. It is com-



Time-Work-Hardening Test.

<i>Passes of Ball :</i>	0.	2.	4.
Time-hardness	25.8	35.5	35.4

FIG. 3.—Worn Rail. Time-Hardness induced by Wear.



Time-Work-Hardening Test.

<i>Passes of Ball :</i>	0.	2.	4.	6.
Time-hardness	26.6	34.6	35.0	34.7

FIG. 4.—Worn Rail. Time-Hardness induced by Wear.

mon practice to employ manganese steel for points and crossings, this steel being soft, but possessing an abnormally high work-hardening capacity (see Tables I. and II.).

B. Superhardening of Hard Steel Gears and Cams.—Investigation was made of a number of worn gears and cams which had been discarded from automobiles. The procedure was to make diamond time-hardness tests with the pendulum on the worn and unworn surfaces. In the case of gears, a particular tooth was selected, and the adjacent teeth on either side were ground away so as to expose the selected tooth and allow the pendulum to be balanced on any part of the worn surface. The selected tooth was then cut out by grinding with a thin emery-wheel flooded

with water. The tooth was mounted in pitch, a section was made by hand-grinding, and this was polished, etched, and tested for hardness at many points with the pendulum and a 1-mm. diamond. The cams were dealt with in a similar manner, worn and unworn surfaces being first tested for hardness, and sections being made through the worn portion.

Photographs of teeth from three worn gears are shown in Figs. 7, 8, and 9 (Plate XVI.), and charts giving the results of the hardness tests in Figs. 7A, 8A, and 9A. The diamond time-hardness corresponding to each of the test impressions can be readily seen from the charts, and the results of hardness tests made on the surface are also given, with arrows to indicate the approximate position of the test.

Diamond time-work-hardening tests were made on the unworn ends of the teeth of each gear and gave the following results :

<i>Passes of Diamond :</i>		0.	2.	4.	6.
Gear B (Fig. 7) diamond time-hardness	.	<u>36.2</u>	54.4	<u>57.1</u>	57.0
Gear C (Fig. 8)	„ „	<u>35.5</u>	<u>51.2</u>	50.8	...
Gear D (Fig. 9)	„ „	<u>36.0</u>	52.6	<u>53.9</u>	53.3

It will be seen from these figures that all the teeth investigated were very much superhardened by use, the hardness being greatest on the surface, but extending an appreciable distance below the surface.

In each case there was clear evidence that the hard steel had been caused to flow by the shock of engaging the gears (all the teeth were from change gears, and had been rounded to facilitate engagement), and this flow is even more clearly seen in Fig. 11 (Plate XVII.), which shows the flowed steel at the point of gear tooth B, and in Fig. 12, which shows the pitch point on gear C where the principal shock occurred.

The results of this investigation are summarised in Table III. :

TABLE III.—*Diamond Time-Hardness of Three Gear Teeth.*

	Original Hardness.		Induced by Service.		Induced by Pendulum.	
	Time.	Brinell.	Time.	Brinell.	Time.	Brinell.
Gear B .	36.3	490	58.5	790	57.1	771
Gear C .	35.9	485	48.6	657	51.2	690
Gear D .	36.2	489	53.6	723	53.9	729

The average original hardness of each tooth is given, together with the highest hardness reading obtained on the surface, and the maximum induced hardness given by the diamond time-work-hardening test. In each case the diamond time-hardness number has been multiplied by 13·5 to give the approximate Brinell hardness. From these figures it appears that—

- (a) The original hardness of the three gears was nearly equal.
- (b) Their capacity for work-hardening was very different.
- (c) The maximum hardness induced by wear and the maximum hardness induced by the pendulum were in the same order and corresponded closely.
- (d) The original hardness gave no indication of the hardness that would be induced by wear.
- (e) The original hardness of the gear could have no importance in relation to its resistance to wear, since steel possessing the original hardness did not exist in the worn surfaces.

A similar investigation was made with two worn cams from automobiles. Diamond time-hardness tests were made with the pendulum on the worn surfaces of the cams. Sections were cut through the worn portions, and these were polished, tested for hardness, and photographed (Figs. 13 and 14, Plate XVIII.). Diamond time-work-hardening tests were made on the polished surfaces, and the impressions made by these tests can be seen in the photographs. Cam G was tested for work-hardening in three positions. Figs. 13A and 14A are charts giving the results of the hardness and work-hardening tests.

The work-hardening test figures were as follows :

<i>Passes of Ball :</i>	0.	2.	4.	6.	8.	10.	12.	14.
Cam F	60·2	79·2	81·3	82·0	85·2	81·8	...	...
Cam G, position A .	27·8	39·1	40·6	40·6	41·6	43·1	43·9	42·6
„ G, „ B .	43·2	65·6	70·1	71·7	68·2	...	...	...
„ G, „ C .	54·5	81·0	83·2	88·7	87·3	...	...	...

The results of the hardness and work-hardening tests on cams are summarised in Table IV.

In cam F the hardness induced on the surface by wear corresponded closely with the maximum hardness induced by the pendulum. Cam G, though originally less hard, had a much

higher work-hardening capacity. The worn surface was intensely hard, but had not reached its maximum. Cam G was much less worn than cam F.

TABLE IV.—*Diamond Time and Brinell Hardness of Two Cams.*

	Original Hardness.		Induced by Wear.		Induced by Pendulum.	
	Time.	Brinell.	Time.	Brinell.	Time.	Brinell.
Cam F . .	60.2	815	86.0	1160	85.2	1150
Cam G . .	54.5	735	75.3	1020	88.7	1195

In this, as in previous cases, it is evident that the original hardness had no importance in relation to wear resistance, since original hardness did not exist in the worn surfaces.

In view of these results, several questions present themselves. Does wear always produce work-hardening? What conditions are most favourable for its production? How does the chemical composition of the steel affect its work-hardening properties?

It seems probable that work-hardening does not occur in hard or soft metals unless abrasion is sufficiently severe to produce permanent deformation or plastic flow of the surface layer. It is known that manganese steel has an exceptional ability to resist abrasion in railway points and crossings, rock-crushing machinery, &c., in which cases abrasion is so severe as to deform the soft steel and work-harden the surface. But manganese steel gives poor results when used for grinding or crushing soft substances such as cement. It is worn away without deformation of the remaining surface, and therefore without work-hardening.

All the gears and cams in the foregoing investigation had certainly been subjected to shock in addition to frictional wear. Investigation of a worn screw gear A, as used for driving automobile camshafts, showed that none of the worn surfaces were harder than the unworn. A time-work-hardening test was made on this gear with the following result :

<i>Passes of Ball :</i>	0.	2.	4.	6.	8.	10.	12.	14.
Diamond time-hardness	49.4	72.4	76.2	76.6	77.8	82.0	82.2	81.4

Thus, screw gear A had a high work-hardening capacity ; it was considerably worn, but had not been hardened by wear, which in this case consisted of frictional abrasion between relatively large surfaces of contact.

The composition of the various gears and cams was as follows :

	Carbon. %	Manganese. %	Nickel. %	Chromium. %	Silicon. %	Sulphur. %	Phosphorus. %	
Screw gear A . . .	0·15	0·35	5·0	0·30	0·30	0·05	0·05	Case-hardened
Gears B, C, and D	0·35	0·50	3·75	1·20	0·20	0·04	0·04	Hardened from 830° C. in oil
Cam F . . .	0·11	0·70	...	...	0·21	0·06	0·02	Case-hardened
Cam G . . .	0·18	0·75	...	...	0·10	0·04	0·04	Case-hardened

It will be observed that gears B, C, and D were supposed to be made of the same steel similarly hardened, but the gears were made at very different periods and must have been differently treated, as shown by the work-hardening test and the micro-structure. Their original hardnesses were nearly equal.

In order to ascertain the effect of the composition of steel on its superhardening properties, a specimen of plain carbon steel (1·25 per cent. carbon) was hardened unevenly and spots were selected, the hardness of which corresponded with the original hardness of each of the gears and cams. On the selected spots time-work-hardening tests were made. The original and maximum induced hardness of each spot is given in Table V., together with the original and maximum induced hardness of the corresponding gears and cams.

TABLE V.—*Comparison of Superhardening Properties of Alloy Steel and Carbon Steel.*

	Alloy Steel.		Carbon Steel.	
	Original.	Maximum.	Original.	Maximum.
Gear A	49·4	82·2	49·6	64·6
Gear C	35·5	51·0	35·5	40·7
Cam F	60·2	85·2	60·6	79·4
Cam G	54·5	88·7	55·4	71·4

From this it appears that in every case the hard alloy steel was capable of attaining a higher induced hardness than plain carbon steel of equal or slightly greater hardness.

The superhardening of hard steel demands much more extended study than it has yet received, but it is hoped that the present research may serve as a useful introduction to a subject of great practical importance.

CONCLUSIONS.

1. In articles of metal which are subjected to severe abrasion in service a surface layer is produced, the hardness of which is much greater than that of the original metal.

2. This increase of hardness occurs not only in articles of soft steel, such as railway tyres and rails, but also in articles of hardened steel—gears, cams, and the like, whether hardened throughout or case-hardened.

3. The degree of hardness induced by wear tends to a maximum which varies greatly in different metals, and in different classes of the same metal.

4. Hardened or case-hardened alloy steels, while differing greatly among themselves in respect to their capacity for superhardening, are generally capable of a higher degree of induced hardness than plain carbon steels of the same original hardness.

5. The capacity of a metal to resist wear, in so far as it depends on hardness, must depend on the hardness induced by wear, and not on the original hardness.

6. The maximum hardness which can be induced in any metal by wear corresponds generally with the maximum hardness induced by the pendulum work-hardening tests.

7. The original hardness of a metal gives no indication of the ultimate hardness of the worn surface.

8. The original hardness of a metal exposed to severe abrasion can have no importance in relation to resistance to wear, since metal possessing that hardness does not exist in the worn surface of contact.

9. It appears probable that work-hardening or superhardening does not occur unless the conditions of abrasion are so severe as to cause some plastic flow of the metal below the abraded surface. Such plastic flow can occur in very hard steel.

APPENDIX.

THE "CLOUDBURST" HARDNESS TEST AND SUPERHARDENING.

The research described in the preceding pages has shown that articles of hard steel, such as gears and cams of motor-cars, are superhardened by the severe abrasion which occurs in service. The investigation of superhardening caused by wear suggested the inquiry whether articles of hard steel could be superhardened beforehand as a means of resisting wear, and the result of the inquiry was the "Cloudburst" invention.

Imagine an atmosphere whose molecules consist of small hard steel balls, flying about with high velocity and colliding with each other and with any object immersed in it. An article placed in such an atmosphere will be subjected to a rapid succession of blows, and if a certain relationship exist between its hardness and the atmospheric pressure—that is, the momentum of the balls—its surface will be compressed without being sensibly indented.

The article, if of hard steel, will become encased in a thin superhardened layer. If the velocity of the balls be now slightly increased, the hard layer will resist indentation, but will be increased in hardness and in thickness. By gradually increasing the velocity of the balls, a superhardened layer can be produced, intensely hard on the surface and gradually decreasing in hardness throughout its thickness, which may be about 2 mm. As there is no abrupt change of hardness, there is no tendency for the layer to scale or flake off.

The actual hardness that can be thus produced depends upon the superhardening capacity of the steel, which is easily measured by the "time-work-hardening test" carried out with the pendulum hardness tester and diamond ball. The ball velocity required to produce this hardness can be determined by experience.

Just as there is a relationship between the original hardness of the steel and the initial ball velocity which compresses the surface without indenting it, so there is a relationship between the maximum induced hardness of the steel as measured with the pendulum, and the final ball velocity which is sufficient to

produce maximum hardness, but is insufficient to indent the superhardened surface. Any further increase of velocity will merely roughen the surface without increasing its hardness, and the whole superhardening process must, therefore, take place between these two limiting velocities.

The process can, of course, be applied to produce a work-hardened layer on any metal by adjusting the initial and final ball velocities to its "original hardness" and its "maximum induced hardness." It may be found applicable to the surface hardening of rails, axles, tyres, turbine blades, the bores of cylinders, and many other structures which are liable to wear.

Fig. 15 (Plate XIX.) shows the superhardened layer in the fractured surface of a piece of high-carbon steel, hardened and superhardened.

Fig. 16 is a micrograph ($\times 20$) of the same specimen, polished, etched, and tested for hardness in five places with the pendulum and diamond. It shows the hardness gradient of the superhardened layer extending to a depth of 1.5 mm. The original hardness 57.2 is equivalent to 770 Brinell. The final surface hardness 75.7 is equivalent to 1020 Brinell. On certain case-hardened steels a maximum diamond-time hardness of 94.6, equivalent to 1275 Brinell, has been produced by superhardening.

Fig. 17 is a micrograph ($\times 20$) of nickel-chrome steel, heat-treated and superhardened. Eleven pendulum test impressions are shown in a depth of 1.7 mm., and the average surface hardness is 53.0. Diamond time hardness 53 corresponds to 715 Brinell. The original surface hardness was 38.8, equivalent to 525 Brinell.

The atmosphere of steel balls was invented and investigated as a means of superhardening. The investigation has revealed another effect of equal importance. The initial ball velocity is so adjusted to the hardness of the work that it is just insufficient to indent the surface. It follows that if any part of the work be soft, its surface will be indented and roughened.

If, for example, a quantity of hardened steel articles be placed in a ball atmosphere of correct pressure, it will be found on removing them that any soft articles or any soft spots can be easily distinguished by their indented appearance.

A new process is thus available, which may become known as Cloudburst hardness testing, whereby large quantities of

hardened articles can be tested for hardness, all at once, and all over, and without marking them except on the soft spots.

The existing Cloudburst testing machine makes 200,000 hardness tests per minute. But this is only a small machine, and the number of tests can be increased indefinitely.

Where quantities are sufficient to warrant it, the work can be carried through the testing chamber on a conveyor, and when it emerges the soft pieces can be identified by visual inspection.

By adopting a higher velocity, all surfaces, hard and soft, may be indented, and the hardness at any point measured by the size of the indentations.

Fig. 18 shows a piece of mild steel case-hardened. The case was ground away at one corner, and the specimen polished. The Cloudburst hardness test showed the soft core, and it also revealed irregular soft patches at the other end of the specimen, but it left the hard surface unmarked.

In Fig. 19 is seen a piece of mild steel, case-hardened and superhardened. The letter H had been painted with a protective compound before carburising, and was decidedly softer than the surrounding surface. The Cloudburst roughened the softer surface and rendered the letter H visible. The reflection of the screw shows the mirror-like superhardened surface.

DESCRIPTION OF THE "CLOUDBURST" MACHINES.

The machines which have been designed for carrying out the work-hardening, superhardening, and hardness testing processes by the "Cloudburst" method are shown in the drawings Figs. 5 and 6. They are of two types, the gravity type, in which the velocity of the balls is controlled by the height of their fall, and the deflector type, in which their velocity depends on the speed of the rotor which sets them in motion.

Referring to the gravity type (Fig. 5), the balls, 20,000 or more in number and 2 mm. or more in diameter, are introduced into the machine through funnel *A*, and after rolling down the incline *B* are struck by the vanes of a rotor *C*, which projects them up a wooden tube; by striking the deflector *D* they are directed into a fixed hopper *E*, their velocity being destroyed by loose rubber curtains *F*. From the fixed hopper the balls fall

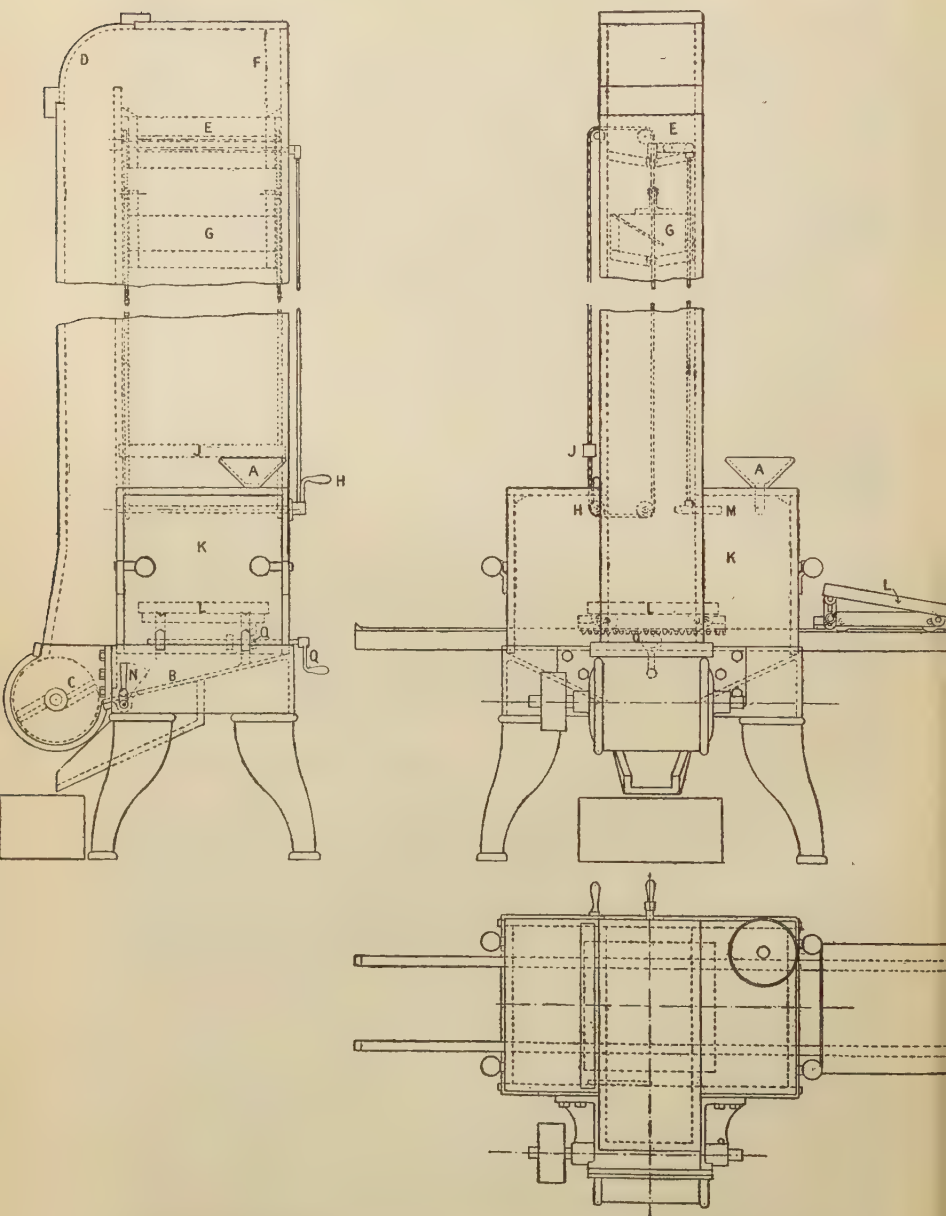


FIG. 5.—Gravity Type Cloudburst Hardness Testing Machine.

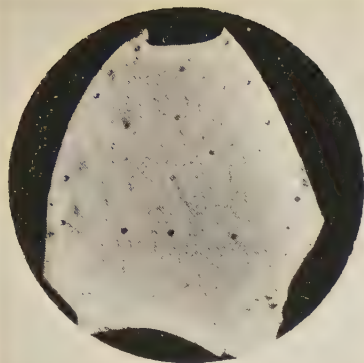


FIG. 7.—Tooth of worn Gear B tested for Hardness $\times 10$. (Reduced to $\frac{2}{3}$.)

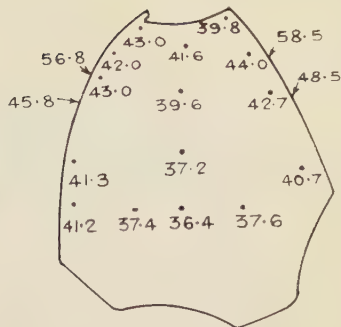


FIG. 7A.—Diamond Time-Hardness of Gear Tooth B.

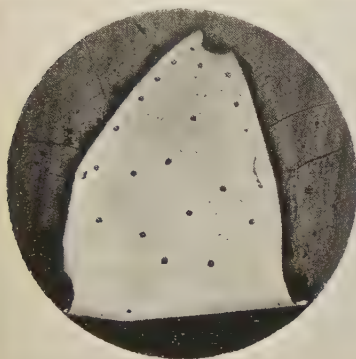


FIG. 8.—Tooth of worn Gear C tested for Hardness. $\times 10$. (Reduced to $\frac{2}{3}$.)

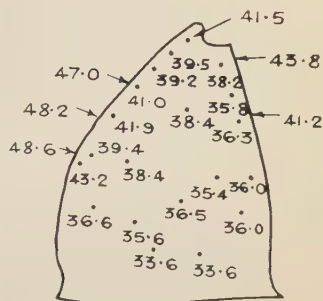


FIG. 8A.—Diamond Time-Hardness of Gear Tooth C.



FIG. 9.—Tooth of worn Gear D tested for Hardness. $\times 10$. (Reduced to $\frac{2}{3}$.)

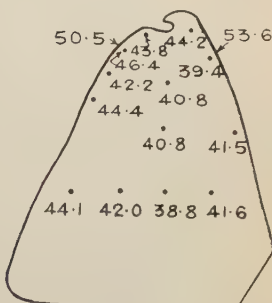


FIG. 9A.—Diamond Time-Hardness of Gear Tooth D.

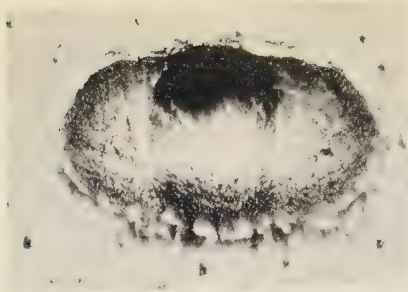


FIG. 10.—Time-Work-Hardening
Test Impression in Mild Steel.
×100.

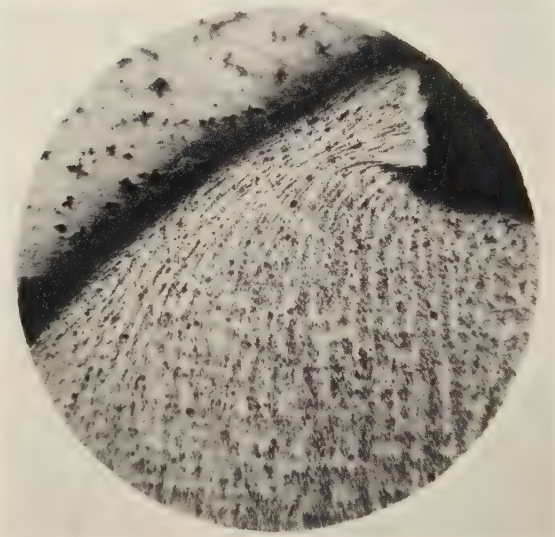


FIG. 11.—Flowed Steel
at Point of hard Gear
Tooth B. ×50.

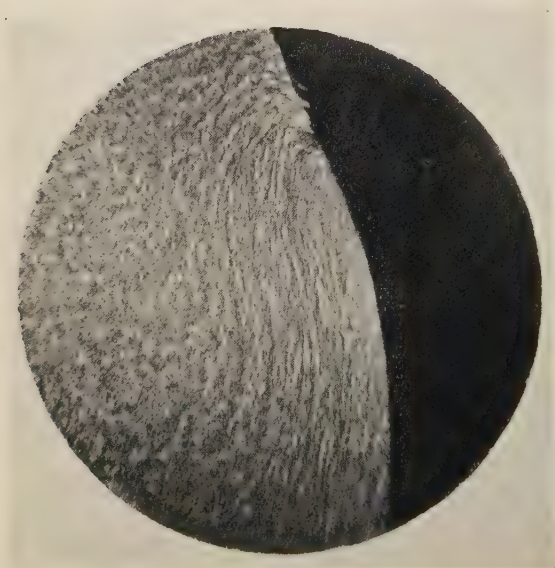


FIG. 12.—Flowed Steel
at Pitch Line of hard
Gear Tooth C. ×50.

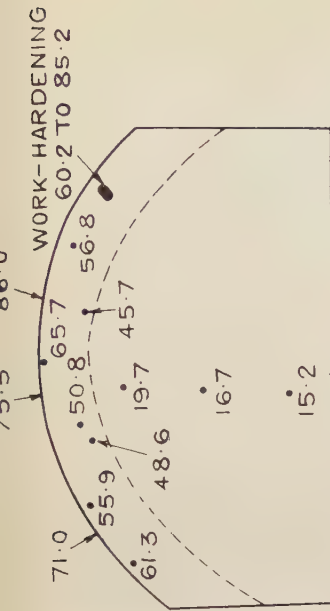


FIG. 13A.—Diamond Time-Hardness of Cam F.

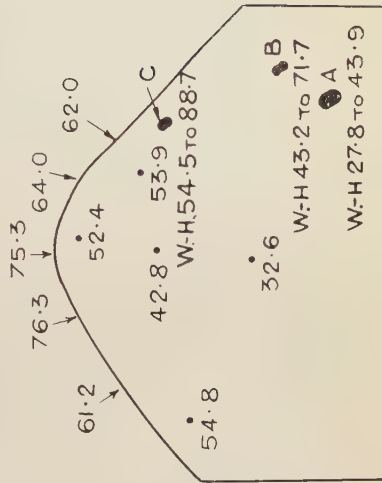


FIG. 14A.—Diamond Time-Hardness of Cam G.



FIG. 13.—Worn Cam F tested for Hardness and Work-Hardening. $\times 10$. (Reduced to $\frac{3}{8}$.)

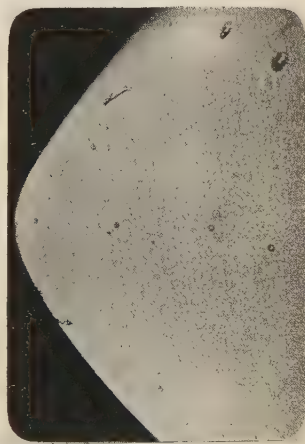


FIG. 14.—Worn Cam G tested for Hardness and Work-Hardening. $\times 10$. (Reduced to $\frac{3}{8}$.)

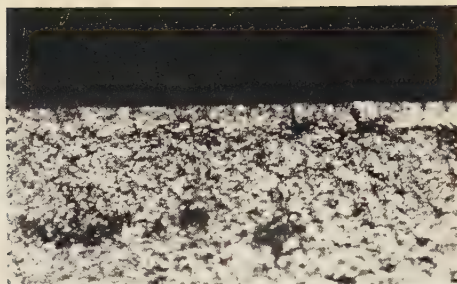


FIG. 15.—The superhardened layer in the fracture of a high-carbon steel, hardened and superhardened.

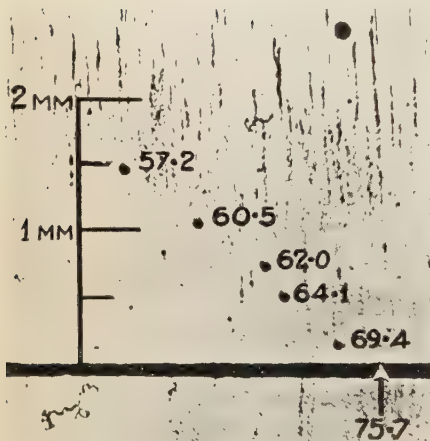


FIG. 16.—The hardness gradient in the superhardened layer of a high-carbon steel (same specimen as Fig. 15). $\times 20$.

Pendulum diamond-time hardness numbers $\times 13.5 =$ Brinell hardness numbers.

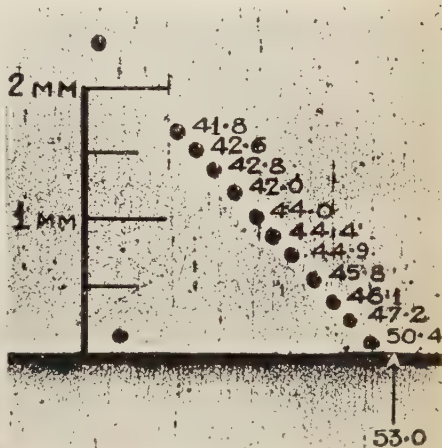


FIG. 17.—The hardness gradient in the superhardened layer of a nickel-chrome steel. $\times 20$.

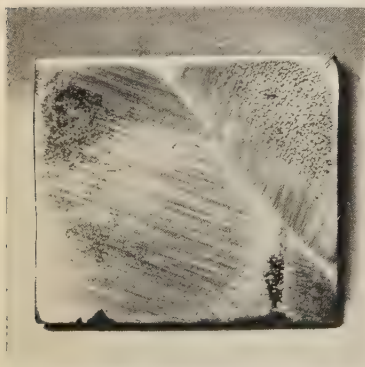


FIG. 18.—Case-hardened mild steel, showing soft core and soft spots revealed by the Cloudburst method.

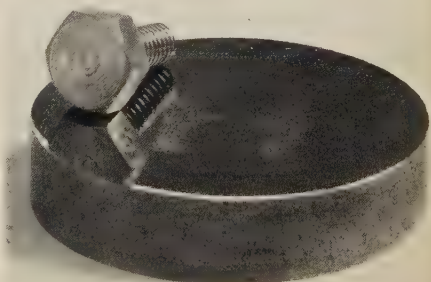


FIG. 19.—Mild steel case-hardened and superhardened. The letter H was left soft and was revealed by the Cloudburst. Note the mirror-like surface of the superhardened case.

through a long narrow slot into a hopper *G*, whose height can be adjusted by the handle *H*, operating through endless chains and

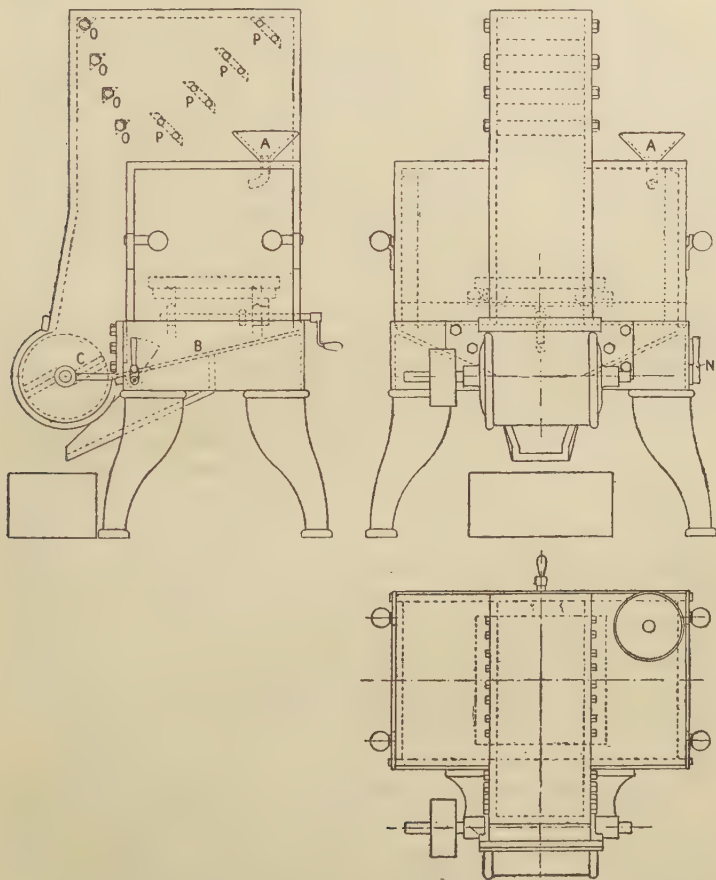


FIG. 6.—Deflector Type Cloudburst Hardness Testing Machine.

sprockets. The height of the adjustable hopper above the work is indicated by the position of the counterbalance weight *J* on a vertical scale affixed to the machine.

The balls falling into hopper *G* are brought to rest by rubber baffles and fall through a long narrow slot in a thin jet into the rubber-lined chamber *K*.

Two work-tables *L* are provided, each being 18 in. square in the small size machine. They can be traversed in the chamber by rack and pinion *Q*, and either table can be run out of the chamber on rails for unloading and reloading while the other table is in the chamber. The tables can be tilted so as to cause the balls to rebound in an inclined direction, thus avoiding interference with the jet descending from above, and preventing the accumulation of balls which would occur on a horizontal surface. The flow of balls can be stopped by operating the handle *M* which closes the slot in the fixed hopper, and the balls can be removed from the machine by turning the handle *N*. A device (not shown) is provided whereby, when the fixed hopper is closed, balls can be caused to fall singly on to an indicated spot on the table, this being convenient for making individual hardness tests and for determining the correct height of fall.

The balls, when spent, again roll down the incline *B* and are struck by the rotor, being thus kept in continuous circulation.

For the purpose of producing a hard, wear-resisting skin on the walls of cylinders and other internal surfaces, and for making internal hardness tests, it is proposed to suspend from the lower hopper conical deflectors of hard steel. The balls falling on the conical surfaces will rebound radially in a horizontal spray, which can be brought to bear on the cylinder walls by lowering the hopper with deflectors attached.

Gears and other cylindrical objects will be treated while mounted on an arbor, which can be caused to rotate by the handle and pinion *Q*.

The deflector type of machine (Fig. 6) is similar to the gravity type, but the balls, after being projected vertically upwards by the rotor, are deflected first horizontally, then vertically downwards into the chamber by pairs of deflectors *O* and *P*. The ball velocity can be regulated by a variable-speed motor driving the machine.

DISCUSSION.

Mr. E. H. SANITER (Vice-President), in opening the discussion, said he had read the paper with very great interest, and the further information given in the Appendix had made it more interesting still. The simple method of testing hardness by the pendulum machine described by the author might prove of very great value as a measure of the wearing properties of steel. He would not like to be too dogmatic on that point at the present time, because before the results could be accepted definitely and with confidence they would have to be correlated with the wearing properties of steels in use.

With reference to Table I., the author showed that all the specimens went up to a maximum hardness and then decreased. One of the points which had struck him as being particularly interesting was that after coming to a maximum they *decreased*. Assuming that the time-hardness test was similar to what occurred in practice, he presumed that first of all they came to a "hard" point and then to a certain "breaking-down" point; and it seemed to him probable that the breaking-down points were more important with regard to wear than the maximum point, because a steel might come to its maximum point and become hard and tough, or it might come to the same point and become very brittle and friable and wear very badly. As no doubt the members were aware, testing was a subject with which he had dealt a good deal in the past. He had reported to the International Congress of Testing Materials in 1912 on wear testing, the investigation being carried out by means of a machine, which he had invented, using rolling friction. It was very interesting to find, with regard to rails, for instance, that the author's induced hardness of manganese steels seemed to put them ahead of others. Personally, in his wear tests to which he had referred, he had found that manganese steels were the most resistant, and that the results agreed with practice. It seemed to him to be shown by the pendulum machine that the hardening of steel by cold-work was exceedingly rapid, and that it was likely to take place before any material wear had occurred. He agreed with conclusion No. 5: "The capacity of a metal to resist wear, in so far as it depends on hardness, must depend on the hardness induced by wear, and not on the original hardness," but he thought it was necessary to be very careful not to overlook the fact that before putting too much confidence in the method the results must be correlated with actual wearing practice.

Mr. J. H. WHITELEY (Saltburn-by-the-Sea) said he had found the paper very interesting indeed. Table I. gave a series of results which, he thought, would have been better shown if they had been plotted in curves. For example, the maximum hardness in the mild steel was

attained after eight passes, but an examination of the figures would show that it was nearly attained after the second pass. A curve would have brought that out very nicely. From Table I. it was clear that the maximum hardness was attained at different rates for different steels, and a set of curves would have made that still more apparent. Did that difference in rate indicate any peculiar property of the steel? Could it be said that the quality of the steel was indicated by the number of passes required to reach the maximum hardness? Another point to which he wished to refer was the slight drop which occurred after the maximum hardness was reached. If the test were continued, was there a progressive fall in hardness? In his own view a certain amount of energy was expended in each pass, part of which was taken up by the steel in hardening and part liberated as heat. Consequently when the maximum hardness was attained most heat would be liberated, which might cause a slight softening of the metal. Mr. Herbert had drawn some conclusions from hardness tests taken on the interior of his samples, particularly those illustrated in Figs. 1 to 4. He suggested that those steels should have been examined for segregation. It was not fair to take a hardness test in the interior of a piece and then compare it with that on the outside without knowing whether the sample was homogeneous. Some time ago he had had occasion to examine a rail which had failed in service. It had been in use for about twenty years on one side of a curve. The flanges of the wheels had worn the rail-head on one side to a considerable distance inwards. Under the microscope there was distinct evidence there of abrasion and of a work-hardening effect on the skin. The failure occurred after the rail had been removed from the one to the other side of the curve. Within a week it had broken in two. His explanation was that the abrasion and hardening had caused a slight crack in the surface. So long as the rail was in its original position the crack would tend to close up rather than spread further, but when the position of the rail was changed, the stresses being then in the opposite direction, the crack would of course develop. If that explanation of the failure were correct, he was afraid that such an example was not a very good recommendation for the new invention which the author had described. It appeared to him that a severely work-hardened surface of steel would be liable to contain incipient cracks.

Professor C. H. DESCH, F.R.S. (Member of Council), thought the paper was a further illustration of the great usefulness of the most ingenious instrument which the author had devised, and which was found to be very valuable as a research instrument, although it was not one that could be entrusted to the care of an unskilful assistant. If by any chance the pendulum were put slightly out of adjustment it took a good half-day to put it right; but it did furnish most useful information, particularly in regard to work-hardening properties. He wished to question, however, whether the paper was really a study of work-hardening by abrasion in the sense in which abrasion was ordinarily

understood. The hardening was produced either by rolling with slight slip, or, as in the author's later experiments, by impact, but always by contact with smooth surfaces—smooth steel balls or round diamonds. On the other hand, when abrasion occurred in practice, there was, as a rule, some cutting edge present. The abrasion was caused largely by roughness of surface or by the actual cutting edges of abrasive materials, such as emery or sand; and so little was known about the process of cutting that they were not justified in saying that resistance to impact or to roll with slight slip was the same thing as resistance to the action of a hard cutting edge. That qualification should, he thought, be borne in mind. One very important result of the work which the author had done lately, and also of the work which Mr. Hultgren had done in Sweden, was the proof that even the hardest steels were capable of very considerable superhardening by cold-work. With regard to the softening after the initial hardening—that is, the passing through a maximum and then falling off—he did not know if the author had observed any slight deterioration of the surfaces due to a tearing action after the pendulum had been rolling to and fro several times. In a very important recent paper by Mr. Tomlinson in the *Proceedings of the Royal Society*, that curious rusting of steel specimens in the fatigue-testing machine had been explained. It had been shown that wherever there was a very minute amount of slip particles in the surface were torn away, but on such a small scale that it was practically a molecular removal of the metal. That was a disintegration of the surface due to a motion differing from simple rolling. That must be occurring in the work-hardening tests of the author, and it was possible that the disintegration went so far that the surface was somewhat damaged. That should be visible under the microscope, if not as cracks then by the accumulation of oxide, and that might explain the falling-off in the hardness. The actual mechanical cold-work-hardening of very hard steels was, he thought, likely to have great practical importance. There were several conditions that were met with in practice which it had been difficult to explain hitherto, but which he thought might be explained by that kind of action occurring during the rubbing of one metallic surface over another.

Dr. A. BRAMLEY (Loughborough) said that following upon Dr. Desch's remarks he desired to mention one point in connection with the theory of the cloudburst method of detecting hardness, upon which a practice that had been in general use for some time for polishing balls in the manufacture of ball-bearings seemed to him to depend. In the final polishing of the balls, different sized balls were placed in a vessel with small scraps of chamois leather. The vessel rotated on an inclined axis and the balls polished one another. After that operation the balls were sorted out into sizes, and they were examined by placing a number of balls on a tray containing a sheet of white matt-surfaced paper. Girls rolled the balls about, and if there were a fault it was immediately

detected without any difficulty by the faulty reflection of the highly polished ball on the surface of the paper ; if there were no fault the ball was perfectly uniform in reflecting power, but the slightest fault showed itself by a lack of reflection. It seemed to him that what happened was that the balls themselves revealed the soft spots by making impressions upon one another, in just the same manner as the author's impressions were produced.

CORRESPONDENCE.

Professor O. W. BOSTON (Ann Arbor, Michigan) wrote : The results in Mr. Herbert's paper as outlined are of distinct commercial and scientific value. We have known for some time that a piece of steel cold-worked by being pulled until a permanent deformation takes place has new physical properties. By this permanent deformation the elastic limit and other tensile properties are materially increased, even as much as 100 per cent. A practical illustration of the increase in tensile properties by cold-working is the relatively recent development in the cold-forging of large gun-barrels ; results more favourable than the shrunk-on-sleeve method are being obtained. Also, brass rod for screw machines is made more free-cutting, so as to permit higher cutting speeds, by a more intensive cold-drawing process.

I have found experimentally that when cutting a chip of steel with a feed of 0.003 in. the force on the tool expressed in pounds per square inch of cross-sectional area of cut is greater by some 100,000 lb. than the ultimate strength of the material in tension, compression, and shear combined. Mr. Herbert has previously shown that the material being torn, sheared, and bent is work-hardened as the chip is formed—that is, the chip is harder than the mass of the material. Also, it has been known that a surface which is burnished or cold-worked by compression has physical properties more desirable (harder and more wear-resisting) than those of the internal structure. A satisfactory method of measuring these properties, however, has been lacking. Mr. Herbert's method, therefore, throws a scientific light on the subject. It would be interesting to know the relation between the surface of a material before and after subjection to surface plastic flow, such as those reported on by Mr. Herbert, and a similar change in tensile properties of a test-piece of the same material, due to a permanent deformation by tension or compression. I believe some of us are at a loss fully to appreciate the values registered by Mr. Herbert's pendulum work-hardness tester, and undoubtedly if expressed in terms of tensile strength or compressive strength, as well as by the Brinell numbers which he has given, it could be more readily interpreted and appreciated.

Further, it would be of interest to know quantitatively, as well as qualitatively, the value of the burnished gear tooth, such as is being produced by the Lees-Bradner Company of Cleveland, Ohio. In

their gear-finishing machine, a gear made of steel is taken from a hobbing machine and is rolled under pressure between two large hardened and ground master gears. A reciprocating motion is provided which feeds the gears being finished forward and back across the face of the master gears. The slight amount of stock left on the teeth in the rough hobbing operation, which would usually be left for finishing, is displaced and an accurate tooth form and spacing produced. This gear of correct form and size has the advantages of induced hardness at the beginning of its use, such as is found in the worn gear. The resulting surface is similar to that indicated by the author on the outer edge of the locomotive tyre, as well as on the gear teeth which he has measured.

All of these problems seem to have a great deal in common, although in some instances the temperature rise is of more importance than in others, and I hope that the work, covering more of the many practical applications, may be continued, to discover further the laws fundamental to the behaviour of metals.

Dr. W. H. HATFIELD (Member of Council) wrote: Mr. Herbert kindly loaned one of these instruments for the purpose of determining whether it could find a useful place in the equipment of the Brown-Firth Research Laboratory. Tests were accordingly made to check the capabilities of the instrument.

Time-hardness tests were made on several materials of varying hardnesses and compared with their corresponding Brinell hardness numbers. This test placed the materials in the right order, as judged by the Brinell determinations, although they did not quite fit in quantitatively with the relations between time-hardness number and Brinell number given by the makers. This discrepancy was very large in the case of the softer specimens, as indicated by the following three tests:

<i>Specimen.</i>	<i>Time-Hardness Number.</i>	<i>Brinell Number.</i>
327C	17.8	220
331C	14.8	171
332C	14.7	158

These time-hardness numbers were obtained with the diamond indenter. Using the expression $B = CT^2$ recommended for materials below 33 hardness, and taking the results of 327C, we get $C = 0.69$; whilst for 331C it works out to be 0.88, and for 332C, 0.86. These figures are between two and three times the value given for the constant C by the makers, though this refers to a steel ball. If we use the expression given for a diamond indenter on hard specimens, namely, $B = 13.5T$, we get values for the equivalent Brinell number equal to 240, 200, and 198 respectively. From these tests and others we have made, it is apparent that it is unsafe to attempt to convert time-hardness numbers to Brinell numbers.

It was thought, however, that, since we now have methods of determining the hardnesses of all sizes and shapes of specimens, the

pendulum tester might find other uses than ordinary hardness tests. For example, the time-work-hardening test is claimed to measure the induced hardness which the specimen is capable of attaining by cold-work, and the scale work-hardening test measures the increase in hardness resulting from repeated rolling on the same spot, and measures the potentiality to acquire increased hardness by cold-work. These two tests were accordingly applied on the above three samples and compared with the tensile and compression tests on the same materials. The following results were obtained :

Specimen.	Yield Point. Tons per sq. in.	Maximum Stress. Tons per sq. in.	Elongation. %	Reduction of Area. %	Time Tests.		Scale Tests.	
					1.	Mean of 2, 3, and 4.	1.	Mean of 2, 3, 4, 5, and 6.
327C	18.2	47.1	29.0	29.6	17.8	36.0	{ 6 6	36.0 45.6
331C	18.45	43.8	61.0	58.2	14.8	23.5	{ 4 4	31.0 46.0
332C	15.4	39.6	64.5	73.4	14.7	15.7	{ 7 6	10.4 13.2
Load to Produce Compression of—								
	10%.	20%.	30%.	35%.	40%.			
327C	14.05	27.5	38.9	44.95	...			
331C	11.65	19.2	28.05	33.0	37.35			
332C	9.55	15.9	24.25	28.45	32.1			

Both the tensile and compressive tests indicate the same order of placing of the work-hardening capacity of these three materials, as is indicated by both the time and scale work-hardening tests, but there appears to be no quantitative correlation between them.

A further possibility for the application of the instrument was tried—namely, the determination of the hardness of materials at elevated temperatures. Tests were made with the instrument, using the diamond indenter, and directly compared with Brinell impressions, using a diamond ball of 1-mm. diameter and 30-kg. load. The following results were obtained :

	Temperature. ° C.										
	20	100	150	200	250	300	350	400	450	500	600
"Staybrite."											
Brinell number	142	124	126	121	118	112	114	113	114	111	99
Mean of three time tests	14.6	14.7	14.8	13.3	11.5	13.7	14.3	14.5	14.6	14.7	14.0
Mild steel.											
Brinell number	169	161	157	158	167	177	164	177	173	...	...
Mean of three time tests	15.1	14.5	15.2	15.7	15.7	17.0	15.9	16.7	17.1	...	...

The results of the two types of tests do not compare favourably in the case of "Staybrite," but there is some agreement in the case of the mild steel. The determinations at the higher temperatures were somewhat affected by the scale formed, and it is possible that this offers some explanation of the difference in results. As regards the adaptability of the machine, it may be stated that the instrument possesses the advantages of portability and applicability to specimens both large and small and of intricate design. The impression made does not appreciably affect the surface of the specimen, and the tests are not affected by the manner of supporting the specimen so long as it does not move during the test. On the other hand, the setting of the instrument is delicate, and it is somewhat difficult to calibrate. It is hardly considered a workshop instrument, since it needs very careful handling, and, unless it is placed on the test-piece very gently, inertia effects play a considerable part. The exact timing of the period of swing is not an easy matter, even with the excellent stop-watch supplied with the instrument, since the logarithmic decrement of the amplitude of swing in most cases is considerable. It was found best to observe the times when the bubble passed its mean position, rather than its end positions, as recommended by the makers.

Mr. E. G. HERBERT, in replying, agreed with Mr. Saniter as to the desirability of correlating the hardness induced by wear in rails and tyres with their wear-resisting properties, as shown by records of service. He had in fact endeavoured to obtain the records of mileages of the worn-out rails and tyres which he had investigated, but unfortunately the figures were not available.

He was unable to explain the fact that all metals of which he had experience could be work-hardened up to a maximum which was followed by a decrease. He had reason to believe that the decrease might in some cases be due to a breakdown of the material, but generally the decrease was slight, and might even be followed by a rise to another maximum a little higher than the first, if the rolling process were continued. He was unable to agree generally that "the breaking-down points were more important with regard to wear than the maximum point." Figures given in the paper showed that the decrease was quite marked in manganese steel, to the wear-resisting qualities of which Mr. Saniter bore witness.

He agreed with Mr. Whiteley that the figures in Table I. might have been accompanied by a set of curves, which would have brought out more clearly the very different rates at which work-hardening took place in different metals. The rate of work-hardening was undoubtedly a characteristic of particular steels, some specimens regularly attaining their maximum after two or four passes of the ball and other specimens requiring twenty passes to harden them fully. He was quite unable to say whether quick or slow work-hardening was the more desirable characteristic. He had never found a progressive fall in hardness after the maximum was passed, but usually a fluctuation

about, or slightly below, the maximum. In practice the first fall in hardness was taken as an indication that the maximum had been reached, and the test was not continued beyond that stage. He had given particular attention to the measurement of temperatures which might be generated by the work-hardening test, and had satisfied himself that the rise of temperature was so slight as to be barely perceptible by the most sensitive instruments. It was certainly not sufficient to soften the metal.

The incident referred to by Mr. Whiteley—the work-hardening of a rail on one side and its failure when placed in a reversed position—might be a good illustration of the dangerous effect of local work-hardening, a well-recognised cause of failure. The process he had described was rather of the nature of a uniform case-hardening, and he did not anticipate that any such ill effects would follow. He had examined microscopically many specimens which had been hardened by the bombardment process, but had never observed incipient cracks.

Dr. Desch had referred to the time required to adjust the pendulum. In order to put the matter to the test he (Mr. Herbert) had removed the ball from a pendulum, replaced it with a new one, and rebalanced the instrument, timing himself with a stop-watch. The time was 95 seconds, but he would be prepared to allow several seconds more to anyone less experienced than himself. On the question of terminology, which Dr. Desch had raised, he had used the word “abrasion” to describe the wearing action which took place between gear-teeth, or between tyre and rail, and he believed this was correctly described as “abrasive action,” but the term “abrasion” was a very wide one, and in using it he did not intend to imply any analogy between rolling action and the action of “abrasives” such as sand or emery. He was familiar with the curious copper-coloured appearance which often manifested itself on steel which had been fatigued, but he had never observed anything analogous in impressions made by the work-hardening tests.

He had searched Dr. Hatfield's communication in vain for any reference to “the work-hardening of steel by abrasion,” and he thought it would be scarcely appropriate to follow him into a discussion of the merits and demerits of the pendulum hardness tester. He had used this instrument in the present research because it was the only one with which the investigation could have been carried out, and he had in many cases converted the pendulum hardness numbers into approximate Brinell numbers for the convenience of those who might be more familiar with the latter scale of hardness. He should perhaps have explained that the Brinell scale to which he had converted was the “steel ball Brinell” in which a 10-mm. steel ball was used with a 3000-kg. load. Different formulæ were required to convert “diamond time-hardness numbers” and “steel ball time-hardness numbers” into Brinell numbers, because the diamond, owing to its greater rigidity, invariably made a larger impression and gave a lower reading than the steel ball.

It had been shown by Dr. Mailänder and others that similar differences existed between the Brinell numbers obtained with a steel ball and those obtained with a diamond ball. Dr. Hatfield had used a diamond ball for his Brinell tests, and before he could test the accuracy of the formulæ given for converting time-hardness numbers into steel ball Brinell numbers, it would first be necessary to evolve a formula for converting his diamond Brinell numbers into steel ball Brinell numbers. None of the formulæ quoted by Dr. Hatfield were used for the conversion of the diamond time-hardness of soft steels such as those instanced by Dr. Hatfield, and the conversion of pendulum hardness into diamond Brinell hardness had not yet been attempted.

Hot hardness tests were rather outside the scope of the paper, but as Dr. Hatfield had drawn attention to the use of the pendulum for measuring the hardness of red-hot specimens, he might have explained whether, in making his comparative Brinell tests, he removed the specimens from the furnace and allowed them to cool before measuring the impressions, or whether he applied the microscope to the specimen while red-hot in the furnace. It would appear that in the former case the accuracy of the measurements might be affected by oxidation, and in the latter case by considerations of another order.

He appreciated Professor Boston's communication, and particularly his reference to the favourable results obtained by the cold-forging of large gun-barrels, and to his measurements of the vertical force on a cutting tool in relation to the properties of the material it was cutting. He had not yet investigated the teeth of gears finished by the rolling process, but understood that through the kindness of Professor Boston he was soon to have an opportunity of doing so. There seemed no reason to doubt that if the process could be applied to gears of hard steel so as to produce a surface not only accurate in form but super-hardened, the gears would be found to possess exceptional properties under severe conditions of service.

THE SOLUTION OF CEMENTITE IN α -IRON AND ITS PRECIPITATION.¹

By J. H. WHITELEY, F.I.C. (SALTBURN-BY-THE-SEA).

THE extent to which carbon is soluble in α -iron is a question which has, so far, not been satisfactorily settled. Whilst admittedly it cannot in any case be large, metallurgists are by no means agreed on the exact amount. Recently Sauveur² stated that in ordinary steels ferrite contains 0.06 per cent., and Hatfield³ said that between 0.04 and 0.05 per cent. is present. Both these statements were based on the non-observance of cementite in steels of these carbon contents. In the present paper a number of observations are recorded, which indicate very definitely that, at any rate above 680° C., α -iron does dissolve an appreciable quantity of cementite. It is somewhat surprising that the effect produced by the precipitation of this dissolved carbide at lower temperatures appears hitherto to have been overlooked.

The observation which first directed the author's attention to the subject was made while examining a specimen of mild steel which had, for a certain purpose, been twice heated to 680° C. and quenched in water. Minute particles of cementite, readily stained with hot sodium picrate, were seen under a high magnification at the grain boundaries. This effect was quite unexpected because it was completely absent after the first quench, and a considerable amount of work was done before it became clear that solution of cementite in α -iron at 680° C. was the real cause. During the investigation a dozen or more different steels were experimented with, but, as similar results were obtained with all, attention need only be directed to those most frequently used. A description of these is given in Table I.

¹ Received May 26, 1927.

² *Journal of the Iron and Steel Institute*, 1925, No. II. p. 313.

³ "The Physical Chemistry of Steel-Making Processes," *Transactions of the Faraday Society*, 1925, vol. xxi. p. 272.

TABLE I.

Description.	Com- bined Carbon. %	Silicon. %	Phos- phorus. %	Sulphur. %	Man- ganese. %
A. Basic steel of the "Armco" type .	0.035	Trace	0.006	0.026	0.02
B. Acid steel plate heated to 1000° C. and air-cooled	0.18	0.018	0.057	0.065	0.56
C. Acid steel plate heated to about 1400° C. and cooled very slowly	0.19	0.018	0.06	0.071	0.54

1. Fig. 1 (Plate XX.) shows the structure of an etched specimen of sample *B* after it had been heated for one hour at 680° C. and quenched in water. On repeating this treatment, the effect shown in Fig. 2 was obtained. It will be seen that the ferrite grain boundaries were now clearly outlined by the presence of minute cementite particles. The same area, after staining with sodium picrate, is shown in Fig. 3. Cooling the piece down in the furnace to 680° C. from above A_3 before the first quench made no difference, provided the subsequent cooling to room temperature was sufficiently rapid. This was found to be an essential condition; when the rate was such that the specimen reached approximately 100° C. in less than one minute, these cementite particles were to be observed between the grains, but not when the time was increased to two minutes. Further, the effect was produced equally well when the specimens were quenched the first time from temperatures somewhat above Ac_1 , but for the second treatment it was found necessary to keep below that point. Only very short heatings were then required, a stay of one minute at between 660° C. and 680° C. being sufficient. After a prolonged second heating no increase in the quantity of this cementite could be detected; the particles were larger but less numerous.

These facts having been established, the problem was to discover the nature of the change during the second heating which caused the rapid appearance of cementite at the grain boundaries. Solution of carbon in α -iron seemed the most probable explanation, but no clear picture of what took place could at first be formed. Eventually, an insight into the processes at work was obtained by heating the quenched specimens

the second time at progressively lower temperatures, as indicated below, and then making a very careful examination of the ferrite grains.

Between 650° C. and 550° C. it was found that the effect could still be produced in one minute, and, moreover, a distinct increase in the amount of "boundary cementite"¹ was noticeable at the lower temperatures. That produced in sample *B* after it had been heated for one minute² at 560° C. is shown in Fig. 5; a much longer heating made no appreciable difference. When a specimen of the same steel was heated for twenty minutes at 450° C. boundary cementite was again found to be present, but to a lesser extent. At this stage it was noticed that a great number of particles too small to be identified were present in the ferrite grains. It was further seen that at places adjacent to the pearlite areas these particles were much less numerous, for the ferrite there was almost clear. An illustration obtained from sample *C* is given in Fig. 6 (Plate XXI.). On heating specimens at 350° C. a still greater quantity of these fine particles was seen, while boundary cementite was now almost entirely absent, as shown in Fig. 7. This discovery at once suggested that a cloud precipitation of cementite dissolved by the α -iron in the first heating at 680° C. had occurred, and that it was the movement of this precipitated cementite out of the grains at higher temperatures which caused the formation of the boundary cementite. Evidence obtained by further experiments with different steels fully confirmed this conclusion.

Precipitated cementite could be seen in the ferrite of specimens which had been heated for four hours at 250° C., but no indication of any outward movement at that low temperature could be detected. The minute particles appeared to be very uniformly distributed, and boundary cementite was completely absent. A similar effect was obtained by heating for a short time at 350° C., but after twenty minutes at this temperature a little boundary cementite appeared, as shown in Fig. 7. As the temperature was

¹ The term "boundary cementite" is used throughout to denote the minute cementite particles which appear at the grain boundaries under the conditions of heating described.

² In this and all subsequent references to times of heating, the time required to bring the specimen to the temperature stated is not included. It usually took about two minutes to reach 680° C.

raised further, the time required for the whole of the precipitated cementite to move to the grain boundaries steadily diminished until, when 500° C. was passed, the movement became extremely rapid.

A few tests were made in order to determine whether initial precipitation at a low temperature seriously interfered with the rate of the subsequent movement at a higher temperature. Two pieces of the same steel were quenched from 720° C., and one was heated for three minutes at 450° C. ; they were then both heated for one minute at 550° C. and compared. As far as could be judged, the initial precipitation at 450° C. did not cause any appreciable retardation of the migration. In each case the ferrite grains were practically free from visible cementite particles.

2. The surprising rapidity of the cementite movement to the grain boundaries after precipitation recalled some observations recorded by the author in a paper on martensite.¹ It was there shown that, on reheating at 600° C. small mild steel specimens which had been rapidly cooled in hydrogen from 900° C., the carbide particles in the sorbitic grains very quickly found their way to the margins. The author has recently come across a striking instance of the same effect in a quickly cooled acid steel bath sample containing 0.20 per cent. of carbon. A spoonful of metal with a layer of slag on top was withdrawn from the furnace and cooled by immersion in water. When sectioned vertically, the sample was found to have a uniformly sorbitic structure for some distance below the upper surface ; then, for a short distance further in, the retardation of the rate of cooling had been sufficient to allow time for the carbide particles of the sorbite grains to move to the boundaries. The two structures are shown in Figs. 8 and 9 (Plate XXI.). Since the time taken in cooling the sample was not more than thirty seconds, it is very evident that the carbide must have moved to the margins after precipitation with great rapidity.

Another instance from which the same remarkable speed of movement may be inferred was noted during the present investigation. It was found that if the specimens after the first heating were air-cooled to about 100° C. in one minute or less, boundary cementite was usually produced, and a second heating was not required. With this rate of cooling, the temperature

¹ *Journal of the Iron and Steel Institute*, 1925, No. I. p. 329.



FIG. 1.—Sample *B* quenched once from 680° C. $\times 850$.



FIG. 2.—Sample *B* quenched twice from 680° C. $\times 850$.



FIG. 3.—Sample *B* quenched twice from 680° C. Same area as shown in Fig. 2, stained with sodium picrate. $\times 850$.



FIG. 4.—Sample *B* quenched once from 680° C., re-heated two hours at 550° C. $\times 1500$.

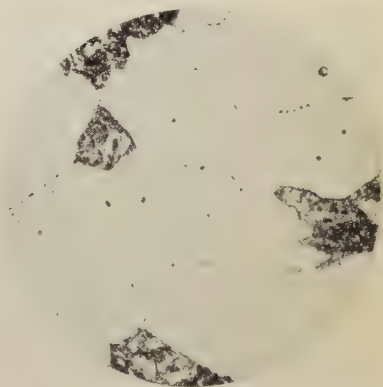


FIG. 5.—Sample *B* quenched once from 680° C., re-heated one minute at 560° C. $\times 850$.

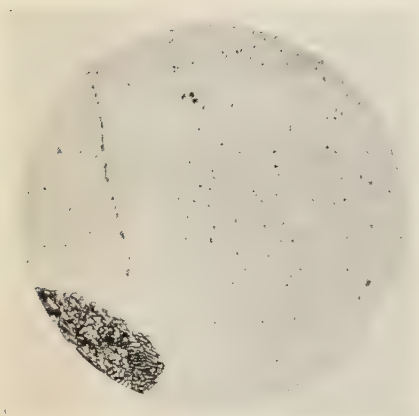


FIG. 6.—Sample C quenched from $720^{\circ}\text{C}.$, re-heated thirty minutes at $450^{\circ}\text{C}.$ $\times 850.$

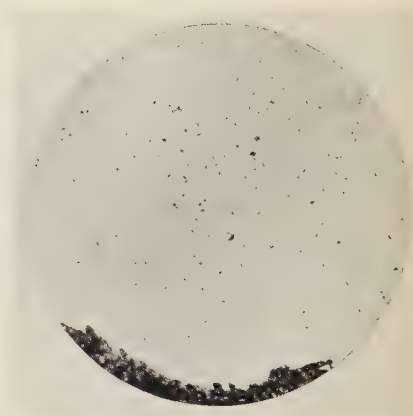


FIG. 7.—Sample C quenched from $720^{\circ}\text{C}.$, re-heated twenty minutes at $350^{\circ}\text{C}.$ $\times 850.$

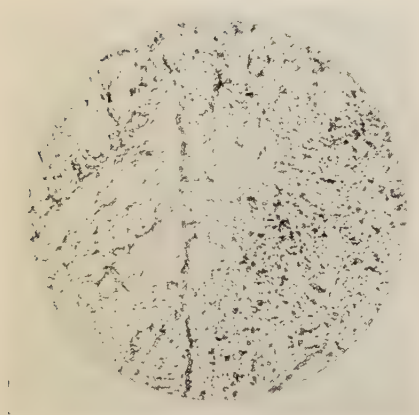


FIG. 8.—Acid bath sample quenched in water; upper part (*cf.* Fig. 9). $\times 850.$

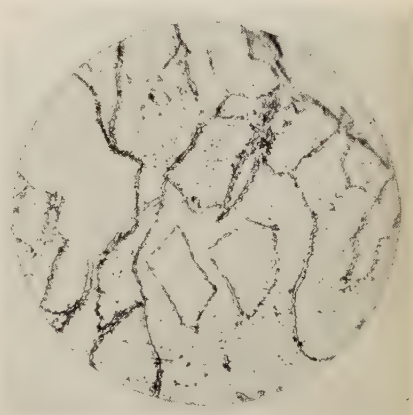


FIG. 9.—Acid bath sample quenched in water; interior (*cf.* Fig. 8). $\times 850.$



FIG. 10.—Sample C air-cooled from 720° C. $\times 400$.

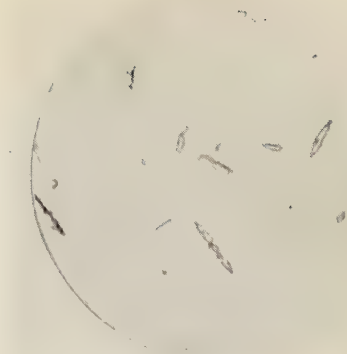


FIG. 11.—Sample C air-cooled from 720° C. $\times 1500$.

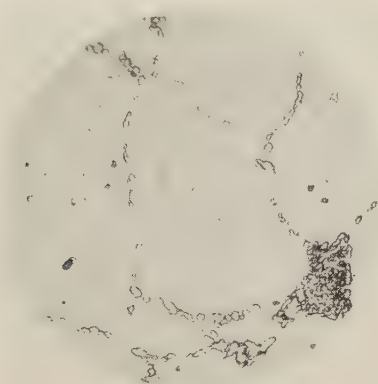


FIG. 12.—Sample B quenched thirty times from 680° C. $\times 850$.

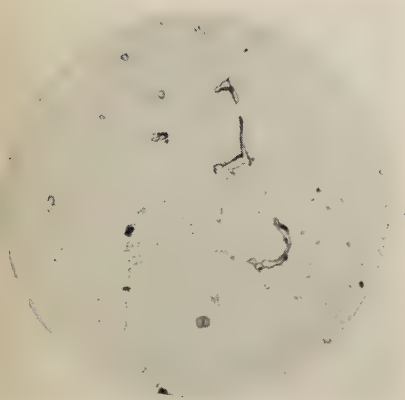


FIG. 13.—Sample A untreated. $\times 950$.

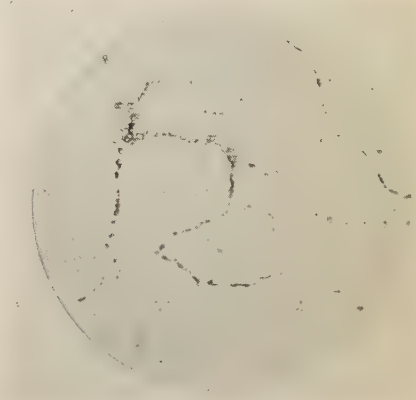


FIG. 14.—Sample A quenched from 720° C., re-heated at 560° C. $\times 850$.

range in which rapid movement occurred would be passed in a few seconds, yet this was evidently sufficient for its completion.

3. In the experiments so far described the temperature of the first heating lay always between 680°C. and 720°C. The next step was to ascertain the lowest temperature at which cementite would dissolve in α -iron in sufficient quantity to produce a visible boundary deposit. Several specimens of different steels were heated for four hours at 600°C. , so as to allow ample time for solution and diffusion of the carbide. After quenching, the pieces were heated for two hours at 400°C. In no instance could either boundary cementite or a cloud precipitation be detected. By gradually raising the temperature, distinct evidence of solubility was first observed in sample *A* after it had been heated at 630°C. , but with other steels, such as samples *B* and *C*, it was not until a temperature of 650°C. was used that any boundary cementite appeared. These tests proved conclusively that the solubility range for α -iron reaches considerably below the A_1 point, and that its extent varies somewhat for different steels. The purer the ferrite the greater this range appears to be. Further, it was clearly seen that the solubility increased with the temperature, for the amounts of cementite deposited at the boundaries in the above tests were much less than the quantities previously observed when higher temperatures were employed.

The same inference was reached when two specimens of sample *B* were examined after they had been heated for thirty minutes at 680° and 720°C. respectively, and then together at 550°C. The latter sample undoubtedly contained more boundary cementite. At still higher temperatures, the diminishing amount of α -iron made a visual estimate untrustworthy. Moreover, above the A_1 point a complication arises from the fact that two solid solutions of carbon are present. The solubility in each must then conform to the partition law. As a consequence, an increase of solubility in the α -iron might be counterbalanced by the diminishing percentage of carbon in the γ -iron; in fact, an experiment indicated that this latter effect actually predominated. Three pieces of sample *B* were heated at 660°C. , 720°C. , and 800°C. respectively and quenched. They were then heated for five minutes at 400°C. so as to avoid the formation of any boundary cementite. It was seen, on examination, that the

amount of carbide precipitated in the ferrite of the sample heated at 800° C. was distinctly less than in the other two.

4. The carbide precipitated at the lower temperatures was always uniformly distributed in the ferrite grains in parts well away from pearlite areas ; no instance was met with where the particles in the centre of the grains were present in an amount less than elsewhere. Even in the case of sample *C*, in which the pearlite areas were widely separated, the distribution of the particles in a specimen heated the first time for one minute only at 720° C. appeared perfectly uniform. Evidently, therefore, carbide dissolved in α -iron diffuses very quickly, and it is for this reason that specimens must be rapidly cooled after the first heating. Otherwise, during cooling, as the solubility diminishes, precipitation will occur on the cementite enclosing the pearlite areas, and few, if any, new crystals will form. The rate of cooling and grain-size are the two factors which apparently determine the position finally occupied by the precipitated cementite, for, obviously, the greater the distance it must travel to reach a pearlite grain, the more likelihood there is of new centres of growth appearing, especially if the cooling is rapid. Thus, when a small section of sample *C* was air-cooled from 720° C., the carbide dissolved by the α -iron was partly precipitated along certain planes in the large ferrite grains, as shown in Figs. 10 and 11 (Plate XXII.). When this specimen was reheated to 680° C. and quenched, the cementite deposited within the grains dissolved, while much of that at the boundaries remained. On reheating a second time to 680° C. and air-cooling, cementite crystals again appeared within the grains.

5. As previously stated, boundary cementite was first seen in specimens which had been quenched twice from 680° C. The explanation of this can now be given. In the first heating cementite was dissolved in the α -iron, and was retained in solid solution by quenching. During the second heating it was precipitated in the early stages, and then rapidly migrated to the grain boundaries as the temperature increased towards 600° C. The speed of this movement is such that there would be ample time for the process to be completed within two minutes, the time occupied in reaching 680° C. It might be expected that the minute boundary particles would dissolve more readily in the

α -iron on passing 650° C. than the much larger masses of cementite enclosing the pearlite grains. In the present case this effect appeared to be outweighed by the extremely rapid rate at which the dissolved carbide diffused in the α -iron. Even after a prolonged heating at a temperature just below the Ac_1 point, the boundary cementite showed no tendency to disappear; the particles merely became less numerous and greater in size, thus indicating that, among themselves, the smaller ones were, in fact, absorbed by the larger. A typical example is given in Fig. 4.

That the pearlite cementite was the main source of supply was demonstrated by repeated heating and quenching. Fig. 12 (Plate XXII.) shows the manner in which cementite particles were distributed in a small section of sample *B* after it had been quenched thirty times from 680° C. Not only has the amount of boundary cementite been greatly increased by this treatment, as can be seen by a comparison with Fig. 5, but also globules now appear within the ferrite grains. Evidently, during the first few quenchings, some nuclei were there formed, and these subsequently grew by continued deposition during each reheating. After ten quenchings they were distinctly visible, but much smaller. The persistence of these nuclei emphasised the fact that the pearlite cementite was, at first, preferentially dissolved. An attempt was made to convert the whole of the pearlite into these globules by further repeated heatings and quenchings, but without success. The result seemed to show that the formation of globules at the expense of pearlite, in this way, ceases long before the latter is used up. Apparently, a state of equilibrium is reached when the amount dissolved off the pearlite is not greater than that deposited thereon during the next heating.

6. The determination of the exact amount of carbon which α -iron can dissolve at different temperatures presents considerable difficulty and has not been included in the present investigation. As previously shown, the temperature of maximum solubility in ordinary steels appears to be in the neighbourhood of 720° C.; also, the indications are that the solubility increases with the purity of the ferrite. But even with the purest iron, it is doubtful whether the amount dissolved ever exceeds 0.03 per cent. This figure has been arrived at by means of sample *A*, which contained over 99.7 per cent. of iron. Its carbon content was very carefully

determined by the combustion method described by the author in a memoir on the Eggertz test.¹ This method is particularly suitable for the estimation of small amounts of carbon, and gave closely agreeing figures. Notwithstanding the low carbon content (0.035 per cent.), small crystals of cementite could be readily observed in the sample under high magnification, as shown in Fig. 13.

When specimens were quenched from 720° C. and examined, it was seen that while there was a diminution in the amount of cementite present, a little remained undissolved. The effect obtained on reheating a piece at 560° C. is reproduced in Fig. 14. Besides the boundary cementite, a cluster of globules formed by the decomposition of a small martensite area is here shown. A few scattered areas of martensite were still to be seen in a piece quenched from 820° C., so that the maximum solubility of carbon in the α -iron of ordinary steels would certainly appear to be less than 0.035 per cent.

Taking 0.03 per cent. as the limit of solubility at 720° C., it is obvious that the amount left dissolved in ferrite after the precipitation has occurred at a lower temperature must be considerably less. The very low solubility of carbon in ferrite at ordinary temperatures was also indicated by an experiment which the author has described in the memoir referred to above. A weighed quantity of drillings of a well-annealed steel, containing 0.37 per cent. of carbon, was dissolved in cold dilute nitric acid. The black residue, consisting of partially decomposed cementite, was at once collected in a Gooch crucible on an ignited asbestos filter, dried, and its carbon content determined by combustion. It was found to be equal to at least 0.36 per cent. in the steel. Now, since carbon in solid solution in the iron would not be included in this precipitate, but would pass at once into the nitric acid solution, its amount must either equal or be less than 0.01 per cent., the difference between the above figure and the total percentage in the steel.

Thus by two diverse methods the same conclusion is reached that the solubility of carbon in slowly cooled ferrite is extremely small. Moreover, the evidence which has been advanced indicates that up to about 630° C. little, if any, change in the degree

¹ *Iron and Steel Institute : Carnegie Scholarship Memoirs*, 1917, vol. viii.

of solubility takes place. It then begins to increase, and at 720°C . its amount is approximately 0.03 per cent. In an interesting paper on the subject, Tamura¹ has lately pointed out that since α -iron and δ -iron have the same space lattice, it is reasonable to consider that "the solubility of carbon in δ -iron at 1486°C . can be regarded as being equal to that of carbon in α -iron, if the latter could be raised to the same temperature." On this assumption and by making use of a recently determined figure for δ -iron he arrived, by extrapolation, at 0.034 per cent. for the solubility of carbon in α -iron at the A_1 point, an estimate in close agreement with that given above.

7. In dealing with the rapid migration of cementite particles to the grain boundaries in Section 2, the manner in which this movement occurs was not discussed. This problem may now be considered. Only two means of transition are possible: either the cementite dissolves in the α -iron, diffuses outwards, and is again precipitated on nuclei at the grain margins, or the minute particles migrate through the ferrite crystals without disintegration under the influence of some unknown force. The evidence available is all in favour of the latter, notwithstanding its seeming impossibility. Solution and redeposition must be, at best, a somewhat slow process, the more so when the solubility is very low, since diffusion gradients cannot then be of any magnitude. Moreover, there appears to be no reason why nuclei, even if present at the boundaries, should grow at the expense of crystals at least equal in size within the grain.

Again, as previously mentioned, the same carbide movement can be induced by tempering mild steels which have been cooled from above 900°C . at a rate quick enough to produce sorbite but not martensite. At 600°C . the sorbite disappears with great rapidity, owing to the migration of the precipitated carbide to the grain margins. On tempering martensite in the same steels at 600°C ., however, the precipitated carbide particles move to the borders of the martensite needles and no further, with the result that the outlines of the martensitic structure can still be seen in the tempered piece if sufficient care be taken in the preparation of the surface. As the temperature is raised towards 700°C . this effect gradually disappears. Apparently, the ferrite needles

¹ *Journal of the Iron and Steel Institute*, 1927, No. I. p. 747.

resulting from the decomposition of the martensite lose their separate existence. Yet, even though the cementite is becoming more soluble in the α -iron, and consequently solution and diffusion should occur more easily, the particles show no tendency to migrate further to the grain boundaries; they merely increase in size. But on the assumption that they have grown too large for individual movement this fact is readily explicable.

8. Although the amount of carbon which can be dissolved by α -iron is small compared with the quantity that γ -iron can hold, it was of interest, in view of the great hardness of martensite, to ascertain whether the hardness of α -iron was increased to any extent by retaining the carbide in solid solution. Several low-carbon steels were examined, repeated tests being made on each. Pieces were heated to 680° C.—that is, just below A_1 —quenched, and tested by the Brinell method. They were then reheated to 550° C. and retested. In some cases this procedure was reversed, the sample being first heated to 550° C. and then to 680° C. Each piece was finally sectioned across the Brinell impression and examined to make certain that the A_1 point had not been reached. In all instances, similar results were obtained, of which the following are typical :

TABLE II.—*Brinell Hardness.*

Sample.	Untreated.	Quenched from—		
		550° C.	680° C.	980° C.
<i>A</i>	89	91	105	116
<i>C</i>	121	121	134	...

These figures show that the presence of dissolved carbide in α -iron has a distinct hardening effect. Sample *C* was selected because of its large grain-size, its freedom from segregation and banded structure, and its widely separated pearlite grains. The hardness of sample *A* after quenching from 980° C. is included for comparison. When quenched from 680° C. a little undissolved cementite remained, but at 980° C. solution was, of course, complete. There can be little doubt that if the whole of the cementite

could have been dissolved in the α -iron, the hardness would have equalled that of the piece quenched from 980° C. It may also be remarked that a careful comparison by the colour test of the carbon in drillings of sample *C* showed a distinct difference between the 550° C. and 680° C. specimens. Using the former as a standard, the latter gave a perceptibly lighter colour, the difference being equal to 0.01 per cent. of carbon. The same result was obtained when this sample was compared with the untreated steel. This "missing carbon" and the increase in hardness both indicate that carbon dissolved in α -iron behaves similarly to that in the martensite of a fully quenched steel.

SUMMARY.

1. It is shown that carbon is soluble in α -iron at temperatures above 630° C. It can be retained in solid solution by quenching; on tempering, precipitation occurs in the ferrite grains at or below 250° C., and as the temperature rises the minute particles thus formed travel to the grain boundaries. The speed of this movement is very great at 550° C.

2. Above 630° C. the solubility gradually increases with the temperature. At 720° C. it is about 0.03 per cent. As the purity of the ferrite is diminished, the initial temperature for solution rises a little, and at the same time the solubility is, in all probability, correspondingly reduced. The rate of diffusion of the dissolved carbide at the A_1 point is extraordinarily rapid.

3. During slow cooling the dissolved carbide is deposited on existing crystals. The inference to be drawn from the observations is that slowly cooled ferrite in ordinary steels contains very little, if any, carbon in solid solution.

4. The presence of dissolved carbon in α -iron increases its Brinell hardness to a small but definite extent.

DISCUSSION.

Dr. W. H. HATFIELD (Member of Council), in opening the discussion, said he had very little to say on the author's most interesting paper, except that the subject with which it dealt was extremely important. The very troublesome point as to whether or not α -iron contained carbon in solution must be settled. It appeared that on separation from the solid solution ferrite did contain carbide, but it appeared from the paper that at the lower temperatures the carbide was thrown out of solution. Whereas it had previously been held that ferrite might, and probably did, contain as much as 0.05 per cent. of carbon, it seemed very doubtful from the result of the author's work whether that were true. Now that the work had been done, it would be very valuable to carry out physical tests on the material under the different conditions mentioned, and he thought it would probably be found that within that range of temperature the mechanical characteristics of the material were actually affected. It was now necessary to endeavour to correlate the two aspects of the matter.

Professor J. H. ANDREW (Glasgow) thought the paper was an exceedingly interesting one, and congratulated the author on his very beautiful photographs; the photographing of masses of cementite as the author had done was extraordinarily difficult. One curious point which had struck him was that the author first heated his steel up to about 680° C., then quenched, and got all the carbon in solution; he then heated it a second time and gradually got it out of solution. In the first heating, the author maintained the temperature of 680° C. for one hour, and that produced a homogeneous structure. He desired to ask the author whether he had ever extended that time; had he ever heated the steel at 680° C. for a day? He also desired to ask whether the author regarded the first heating for an hour or the second heating for one minute as representing the equilibrium condition. The author referred on p. 297 to carbide diffusing through the steel. One would almost take it that the author assumed the carbide to diffuse in small lumps, but surely, before it could diffuse from the interior of the grain to the boundary, it must first go into solution. There were one or two peculiar physical properties to contend with in such a case. In the first place, the moment nuclei of carbide were deposited there was a tendency to get a deposition from solution on those previously deposited nuclei; and, secondly, it was necessary always to contend with the residual valencies at the grain boundaries, which were a source of very strong attraction in themselves. He had noticed the rather peculiar structure of cementite at the grain boundaries of a number of boiler and ship plates submitted to him from time to time, which had been found to be brittle. On examination he found in most of the

cases that the brittleness was due to a continuous film of deposited carbide, but whenever there was a break in the film that brittleness disappeared almost completely. Some people had tried to draw an analogy between the author's work and the work of Dr. Dickie with special steels. Personally, he thought it was impossible to draw a direct analogy, because in special steels it was necessary to consider a concentration of a special element, particularly nickel, at the grain boundary, and it was also necessary to take into account the fact that in special steels a good deal of the peculiar change that occurred was due to a widening of the Ac_1 range, so that he did not think the carbon steel and the special steel cases were truly analogous.

Professor C. H. DESCH, F.R.S. (Member of Council), said that like the author's other papers, the present one contained some very interesting observations, some of which, he thought, it was surprising had not been made before, because it seemed so unlikely that anyone could have missed the facts it contained. There could be no doubt in his opinion, however, that the facts had been quite clearly established. There seemed to be some little difficulty in imagining how the migration to the boundary took place. He entirely agreed with Professor Andrew in thinking that it could not occur without previous solution. He could not imagine particles of appreciable size, of very much more than molecular size, migrating bodily through the space lattice. There must be solution first, but the question arose as to why there should be any migration even when carbide was in solution. He thought it was quite possible that when the whole of the carbide was in solution the state of equilibrium would not be one of homogeneous distribution, but that there would be a greater concentration at the grain boundaries. That would be the case if the effect of the carbon were to lower the surface tension of the metal. The surface tension of solid α -iron was not known, and there were not at present any experimental means of obtaining any reasonable value for it, but if it could be determined, and if it were found that the presence of carbon in solution lowered the surface tension, it followed theoretically that the equilibrium concentration of carbon must be greater at the grain boundaries than in the interior. On cooling, the concentrated solution of carbide at the surface would reach the stage of supersaturation; then the interior of the grain itself would do so, so that the deposition would occur at the grain boundary. That did perhaps supply a possible reason for the migration to the grain boundary. It was, however, very difficult to test. It so happened that in Sheffield they were trying to investigate that question with certain non-ferrous alloys, which seemed to be much easier to experiment with than steels, but it was very difficult to get an experimental proof of such migration. It was, however, just a possibility.

Professor D. HANSON (Birmingham), in congratulating the author on having carried out an extremely nice piece of work, said he imagined

that the members were prepared to accept the evidence which he offered, that carbide could dissolve in and be reprecipitated from ferrite below the critical range. The facts which the author had brought out with regard to the solubility seemed to him to be very similar to what occurred in a number of non-ferrous alloys, notably some aluminium and copper alloys, in which compounds were known to have a considerable solubility at high temperatures and a much lower solubility at a lower temperature. He proposed to endeavour to represent what happened by the use of a simple diagram, which applied in principle to the case the author was investigating (Fig. A).

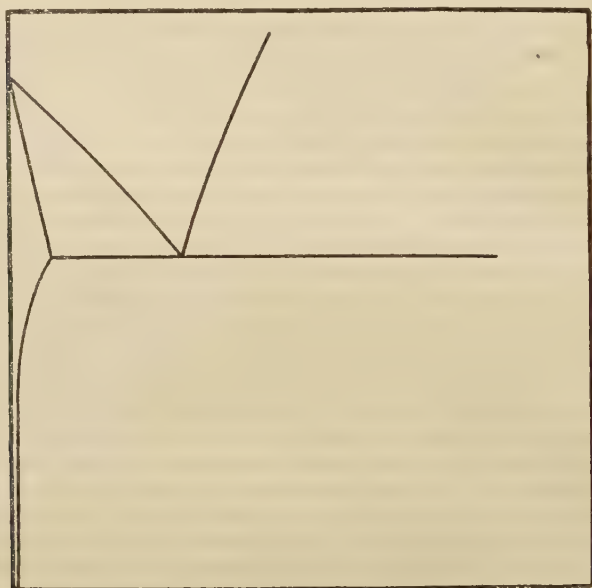


FIG. A.

The diagram represented the ordinary iron-carbon diagram, showing a small solubility at the eutectoid temperature and a fall in solubility as the temperature fell. Such an equilibrium solubility diagram was very similar to that found for a number of aluminium alloys which were capable of undergoing considerable alterations in property by suitable heat treatment. For example, by quenching at a temperature of high solubility and either allowing the metal to stand in air or reheating it to a suitable lower temperature the metal would spontaneously harden. If the temperature were raised slightly the metal passed through a maximum hardness and then softened again as the dissolved compound came out of solution. He desired to suggest to the author that if he

carried out a few simple tests, especially in regard to the age-hardening property of ferrite containing a little carbon, he would obtain further confirmation of the difference in solubility of the carbide. Not only that, but he might find considerably greater hardening effects than were shown by the plain quenching experiments he had done. It seemed to him possible that some of the ageing effects which were known to occur in certain steels well below the critical range might be in part accounted for by the observations the author had put forward.

Dr. H. A. DICKIE (Glasgow) said that he would like to congratulate Mr. Whiteley on his very skilful microscopical work. Mr. Whiteley had demonstrated very conclusively that carbide might separate out of solid solution in ferrite in two distinct forms, either in a fine state of division throughout the mass, by separating out at a relatively low temperature, or at the grain boundaries, by separating out at a relatively high temperature. That was exactly the conclusion which had been drawn from his (Dr. Dickie's) own work on the physical changes concerned in the temper-brittleness of special steels. He thought the only difference between those two cases—the pure materials dealt with by Mr. Whiteley and the complex materials used by himself—was that the separation in either of the two forms took place with greater rapidity when the ferrite was pure than when special elements were present; and that in the case of special steels, where special elements were present in the ferrite, it seemed evident that the carbide boundary, which was produced by separation at a high temperature, was more stable, that is, it was less easily destroyed. In the materials used by Mr. Whiteley the only element which varied much was the manganese. Mr. Whiteley found that an increase in manganese raised the temperature range of solubility, and he also thought that meant that when manganese was added to ferrite the extent of solubility was decreased. Personally, he (Dr. Dickie) did not think the latter conclusion could be correct, because it was well known that a 2 per cent. manganese steel was highly susceptible to temper-brittleness, and he could not think that such marked susceptibility to brittleness could be obtained without a considerable solubility of the carbide in the ferrite at a high temperature.

Mr. E. A. ATKINS (Warrington), in offering his congratulations, said that it was rather peculiar that the author's work should coincide with other work of the kind that had been carried out. Similar work had been done by Dr. Dickie, and for some years he (Mr. Atkins) had been carrying out work on the formation of carbide grain boundaries. Incidentally it was referred to in the paper which he had read before the Institute in the previous May.¹ Reference to that paper would show that his theory in regard to the mechanism of the formation of carbide at the grain boundary was somewhat similar to that which the

¹ E. A. Atkins, "The Drawing of Steel Wire and its Relation to Qualities of Steel," *Journal of the Iron and Steel Institute*, 1927, No. I. p. 443.

author had worked out. Personally, he was more concerned with the practical implications of the formation of carbide at the grain boundary than any other factor. For a great number of years he had had to deal with the manufacture of wire, sheets, and thin plates, and the formation of carbide at the grain boundaries had always been a great trouble. For instance, they manufactured mild steel wire which was used in the manufacture of wire netting. It was beautifully annealed, quite soft, and so on; yet, when it was made into netting and was twisted and rolled up, hundreds of wires would break in a 50-yard roll of netting. Careful examination had shown that to be entirely due to the precipitation of carbide at the crystal boundaries. Again, the same sort of thing might happen in sheets and thin plates. It was found, for instance, that, unless special methods of annealing the sheets were adopted, they very often fractured right across in the straightening machine, and in every case where that had been investigated the ferrite crystals were found to have carbide at the grain boundaries. The investigations made by his (Mr. Atkins') firm had also been directed to finding out ways and means by which steel having a tendency to the precipitation of carbide at the grain boundaries could be annealed, so as to keep the carbide in solution, and that they had succeeded in doing. He was also very much interested in the amount of carbide, so obtained, which the author had found in solution in the crystals, because many times he had examined under the microscope very low carbon steels, containing, say, about 0.03 or 0.04 per cent., and failed to find any pearlite present. Nevertheless, when they had been annealed and were examined again cementite was found at the grain boundaries, confirming the author's statement that the carbide had been in solution, and that at certain temperatures in the cooling it had been thrown out of solution. He desired to mention that intercrystalline brittleness had nothing to do with the brittleness that was set up by a large grain-growth due to critical reduction of area. That point was mentioned very briefly in Professor Edwards' paper, which contained two micrographs showing that when the reduction of area was, in one case, 11.6 per cent., and, in the other case, 16.3 per cent., the grain growth was large. For many years, in the manufacture and annealing of mild steel wires, they had had to be extremely careful in drawing the wires to escape that critical reduction of area between, say, about 10 and 25 per cent.; if they could not escape that critical reduction of area it was necessary to adopt special means of annealing so as not to develop large grain-growth.

Dr. M. L. BECKER (Manchester) said he quite agreed with what Professor Desch and Professor Andrew had said regarding the unlikelihood of the assumption, from the theoretical point of view, that carbide could migrate from the interior of a crystal to the grain boundary without some form of solution. There was just one other suggestion which he desired to put forward, not because he had any particular

proof of its likelihood, but simply because he thought it was a possibility which might be kept in mind. It was conceivable that particles of carbide might be thrust to the outside of the crystal, due to the solubility of α -iron in the carbide itself. There might be a solubility in the carbide principally on one side for one reason or another, perhaps due to the particular orientation of the crystal, and a corresponding precipitation on the other side. He had noticed some evidence that carbide of iron did take iron into solution, at any rate at higher temperatures, because in many large masses of cementite which had been slowly cooled there appeared bands of pearlite, but when quenched from, say, 1000° C. those bands had been very much smaller. He did not say they had been entirely absent in any specimen examined, but they appeared to be very much narrower. He desired to ask a question in regard to Fig. 12, in which the author developed by a number of quenchings the very large particles at the grain boundaries. Could the author state whether by heating to, say, 900° C. or above the A_3 point those carbide particles were entirely dissolved in the iron again, and, if so, whether on cooling they were reprecipitated *in situ* at the grain boundaries or distributed uniformly throughout the grains?

MR. WHITELEY replied that he fully agreed with Dr. Hatfield's suggestion that physical tests should be made on material treated within the range of temperature dealt with in the paper. Besides the Brinell test results given in Table II., he had made a few others in order to discover whether the presence of the boundary carbide particles caused brittleness, but the evidence, so far, was inconclusive. Several references had been made in the discussion to the micrographs. Extremely high magnifications were required, and for his own part he was disappointed with them, though they served well enough to illustrate the various points discussed.

Professor Andrew had inquired whether he had ever heated a specimen at 680° C. for one day. He (Mr. Whiteley) had not done so, nor could he see any object to be gained by it. He had shown in the paper that a very short initial heating at that temperature was sufficient to establish equilibrium conditions, owing to the extraordinary rate at which carbide diffused in α -iron. During the second heating, as the temperature rose, the dissolved carbide was precipitated and found its way to the grain boundaries. As soon as the solubility range was again entered, about 630° C., the existing pearlite areas as well as the precipitated boundary carbide supplied the carbide needed for re-solution in the α -iron; consequently, some of the boundary particles were left undissolved. As stated in the paper, heating for two hours simply increased their size and at the same time diminished their number, but, as far as he could judge, the quantity present remained unaltered. Professor Andrew evidently considered that residual valencies at grain boundaries were of great importance in inducing the carbide movement. He (Mr. Whiteley) failed to see how

that could be, for such attraction could operate only over distances which were insignificant when compared with the size of a ferrite grain. Professor Desch, in suggesting that an increased solubility of carbide at the grain boundaries might be the cause of the migration, had apparently something similar in mind. Surface tension effects ought certainly to be considered. A reduced concentration at the interfaces was, of course, equally possible, and he thought that that would be more likely to bring about the result than the opposite. The great difficulty in the way of accepting such explanations was the speed of the movement; the particles could be transferred to the boundaries in an almost incredibly short time. Moreover, such movement occurred at a temperature well below that at which any solubility could be demonstrated. It could only be extremely small at, say, 550°C ., so that a diffusion gradient of any magnitude, such as was demanded by those explanations postulating solution and diffusion, seemed impossible. For that reason he adhered to the only alternative view that the carbide particles moved bodily out of the grain.

Professor Hanson had raised a very interesting point which was certainly worth investigation. He (Mr. Whiteley) thought it very probable that a small amount of age-hardening could be induced in low-carbon steels by suitable heat treatment. He could not agree with Dr. Dickie's contention that the work described in the paper had a bearing on temper-brittleness in special steels, for in them the carbide remained within the grains even after slow cooling. Definite evidence of any carbide at the boundaries had not yet been produced. In that matter he fully agreed with Professor Andrew's remark that no direct analogy could be drawn between the two cases. He was much interested in Mr. Atkins' observations, and regretted that he had overlooked his published work on the same subject. The idea suggested by Dr. Becker that carbide movement might be induced if α -iron were soluble in carbide was one he had frequently considered, but, so far, he had been unable to make any headway with it. With regard to the effect of heating up to 900°C ., as soon as the Ac_1 point was passed the boundary carbide particles dissolved to form areas of γ -iron. The latter then quickly coalesced and united with the larger areas derived from the dissolved pearlite. On cooling out no boundary carbide was left.

ON THE MECHANISM OF THE TEMPERING OF STEELS.*

BY TOKUJIRO MATSUSHITA AND KIYOSHI NAGASAWA (JAPAN).

1. INTRODUCTION.

MANY investigations on the changes of various properties of quenched steels have been made,[†] and the explanation of the phenomenon of tempering is becoming gradually clear; but the nature of the two-stepped tempering of martensite and of osmondite is not yet well understood.

In the course of the investigation of the physical properties of quenched steels during tempering, the authors observed some unexpected facts which have an important bearing on the elucidation of the phenomenon of tempering. The present paper contains a description of these phenomena, and also a new view concerning the mechanism of tempering.

2. CHANGE OF THE ELECTRIC RESISTANCE AND INTENSITY OF MAGNETISATION DURING THE TEMPERING OF QUENCHED STEELS.

It is a well-known fact that the degree of tempering of quenched steels or of the decomposition of martensite can be precisely followed by measuring the electric resistance or the intensity of magnetisation during the heating.

Generally, the decomposition of a solid solution into its components is accompanied by a decrease of electric resistance, or by an increase of magnetisation. This is also the case in the decomposition of martensite, as the latter substance is a solid solution of carbon in iron. Hence the authors first measured the change of these properties during heating, and from the curves plotted against the tempering temperature, the degree of tempering of quenched steels was measured. With regard to

* Received May 13, 1927.

† See references (1) to (9).

the literature on this subject, the works of Enlund,⁽¹⁾ Saitô,⁽²⁾ and one of the present authors⁽⁴⁾ are to be noted.

The curves in Figs. 1 and 2 show these changes in a quenched carbon steel, the chemical constitution of which was as follows: Carbon 1.02, silicon 0.33, manganese 0.30, phosphorus 0.015, and sulphur 0.022 per cent. The upper curves in these figures were obtained in an experiment in which the heating and cooling were effected at the normal rate. They show that, during the

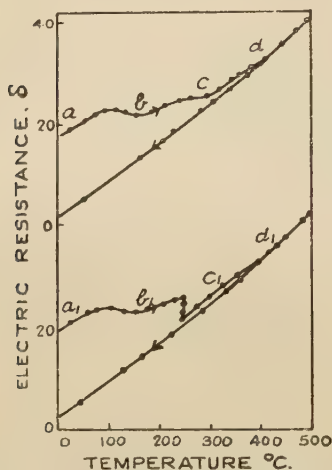


FIG. 1.—Change of Electric Resistance.

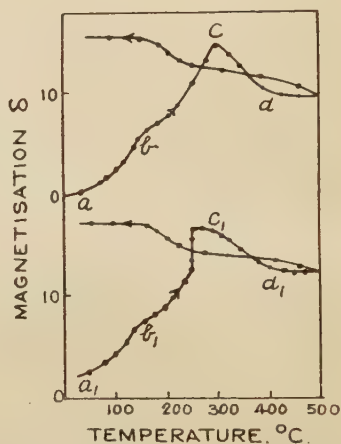


FIG. 2.—Change of Magnetisation.

decomposition of martensite, the electric resistance decreases and the intensity of magnetisation increases, both in two steps below 300° C. From this fact, it is to be concluded that there are two kinds of martensites, α and β , of which the first decomposes mainly in the temperature interval 100° to 170° C., and the second in the interval 170° to 300° C. Martensite, being a forced solid solution of carbon in α -iron, is unstable, and hence when heated it decomposes into its components and precipitates carbon.

The lower curves in Figs. 1 and 2 were obtained at a slower rate of heating than was the case for the upper curves, and by keeping the temperature constant at 250° C. for two hours, during which interval the electric resistance decreases and the intensity of magnetisation increases at the same temperature.

A further heating up to 300° C. does not show any indication of the decomposition of martensite. It is, however, to be noticed that in the curves in Fig. 1 a slight decrease in the electric resistance is observable in the temperature range 300° to 400° C. (cd and c_1d_1), and that in the curves in Fig. 2 the intensity of magnetisation shows a marked decrease in the same range of temperature. As regards the cause of these changes, a very important explanation will be given in the following sections.

3. CONTRACTIONS OBSERVED DURING THE TEMPERING OF QUENCHED STEELS.

The thermal expansion curves of quenched steels give very interesting information concerning the behaviour of the steels

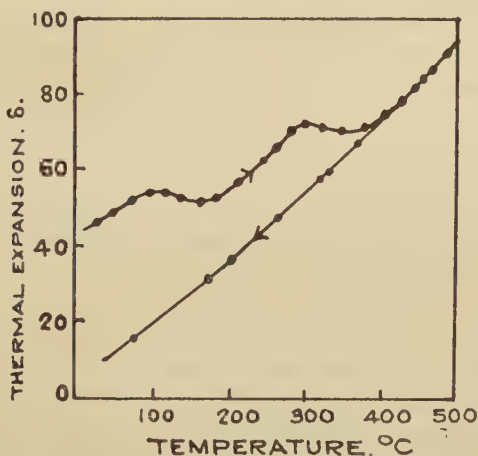


FIG. 3.—Thermal Expansion.

when they are tempered. One of the authors ⁽⁴⁾ first reported on the same subject and afterwards a similar investigation was published by Enlund. ⁽¹⁾

Fig. 3 shows the curve obtained by the authors with the carbon steel mentioned in Section 1, the form of the curve being the same as before. The curves show two conspicuous contractions at 100° to 170° C. and at 300° to 400° C., and they have been considered as two stepped decompositions of martensite,

or those of α - and β -martensites. But according to the present investigation it is confirmed that the second contraction is by no means connected with the decomposition of martensite. The temperature range of the first contraction coincides with that of the changes in the electric resistance or the intensity of magnetisation, but the temperature range of the second contraction does not at all correspond to the change of these properties. Tammann and Schell⁽⁸⁾ also independently observed the same fact, and attributed the second contraction to the vanishing of the voids produced during the tempering of martensite. In the next section, the nature of the second contraction will be considered in more detail.

4. THE CAUSE OF THE SECOND CONTRACTION.

Since the decomposition of martensite is accompanied by an increase of magnetisation, the authors made use of this property to reveal the nature of the second contraction. The experiments were conducted in the following way : A specimen of the carbon steel was first quenched and subjected to magnetic analysis. During a slow heating the magnetisation gradually increased ; at 250° C. the temperature was kept constant for two hours, whereby the magnetisation increased rapidly at first and then gradually, tending to an asymptotic value. This shows that β -martensite is completely decomposed at that temperature. Hence at the end of this period a slight increase of temperature did not cause any increase of the magnetisation. The specimen was then cooled and taken out of the magnetising coil, and placed in the dilatometer. Contrary to expectation, the measurement of thermal expansion during heating showed the second contraction, which occurs in the same range of temperature and has exactly the same magnitude as that of the former experiment. Figs. 4 and 5 are the curves obtained in these two experiments.

If the second contraction be due to the decomposition of martensite, it should vanish after two hours' tempering at 250° C. in the magnetising coil. This not being the case, the second contraction cannot therefore mean the decomposition of the martensite.

As seen in Figs. 1 and 2, in the temperature interval 300° to 400° C. a small decrease of the electric resistance and a marked

decrease of the magnetisation are observable, the latter fact confirming that there is no decomposition of martensite in that interval of temperature.

According to the prevailing view, the carbon in martensite is present in the interspaces of α -iron as carbon atoms, but not as cementite molecules. If so, it is natural to conclude that when martensite is tempered, carbon atoms are at first precipitated as its decomposition product, and afterwards they recombine with iron atoms to form cementite molecules when the tempering temperature is sufficiently raised.

The second contraction at the interval 300° to 400° C. in the

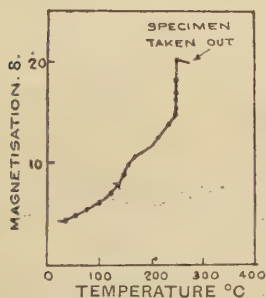


FIG. 4.—Magnetic Analysis.

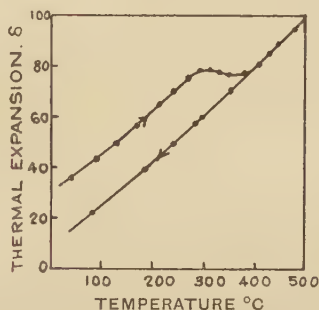


FIG. 5.—Thermal Expansion.

dilatation-temperature curve is very probably the consequence of this recombination, because the specific volume of cementite is less than that of the mixture of iron and carbon.

According to the above view, the decrease of magnetisation and of electric resistance in the temperature interval 300° to 400° C. in Figs. 1 and 2 is easily explained. Thus, since cementite is non-magnetic above 215° C., its formation from iron and carbon must result in the diminution of the magnetisation. Again, the specific resistance of cementite is less than that of a mixture of iron and carbon, and consequently the electric resistance must decrease by the recombination of iron and carbon, as was confirmed by experiment.

To the authors, the view entertained by Tammann and Schell does not seem to be plausible, because the diminution of magnetisation cannot be explained by their view. The authors'

view is also strongly supported, moreover, by the measurement of the magnetic hardness at high temperatures; this will be described in detail in the following section.

5. MAGNETIC HARDNESS AT HIGH TEMPERATURES.

Fig. 6 shows the change of the magnetic hardness (the magnetic coercive force) of quenched steel on heating up to 600° C., the specimen being the same as in the former experiments. As seen from the figure, the magnetic hardness decreases first slowly

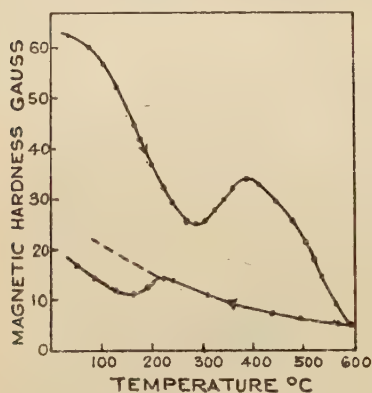


FIG. 6.—Magnetic Hardness of a 1.02% Carbon Steel.

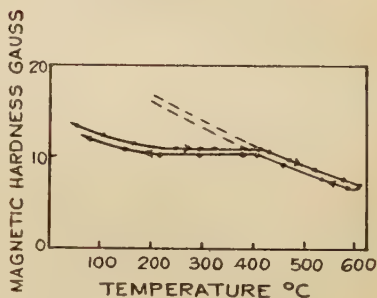


FIG. 7.—Magnetic Hardness of Tungsten Steel (0.7% Carbon, 2.0% Tungsten).

and then rapidly up to 300° C. with the rise of temperature, corresponding to the decomposition of martensite. In the interval 300° to 400° C., a conspicuous increase of the magnetic hardness is seen, corresponding to the second contraction in the dilatation curve, or to the formation of cementite from iron and carbon.

The magnetic hardness of iron increases when it contains dispersed particles of non-magnetic substances. This fact had already been observed by Mathews⁽⁹⁾ in the case of austenite particles scattered in quenched steels of martensitic structure, but here other examples are met with; if the magnetic hardness of an annealed carbon steel during heating be measured, an

abnormal increase is observable at the A_0 transformation of cementite when it gradually transforms into the non-magnetic state. During cooling the opposite change is the case (Fig. 6). Another example is furnished by a tungsten steel, which possesses a double carbide $4Fe_3C.WC$, and has its magnetic transformation point at $400^\circ C.$ ⁽¹⁰⁾

The curves of the magnetic hardness (Fig. 7) measured during heating and cooling show similarly an abnormal increase or

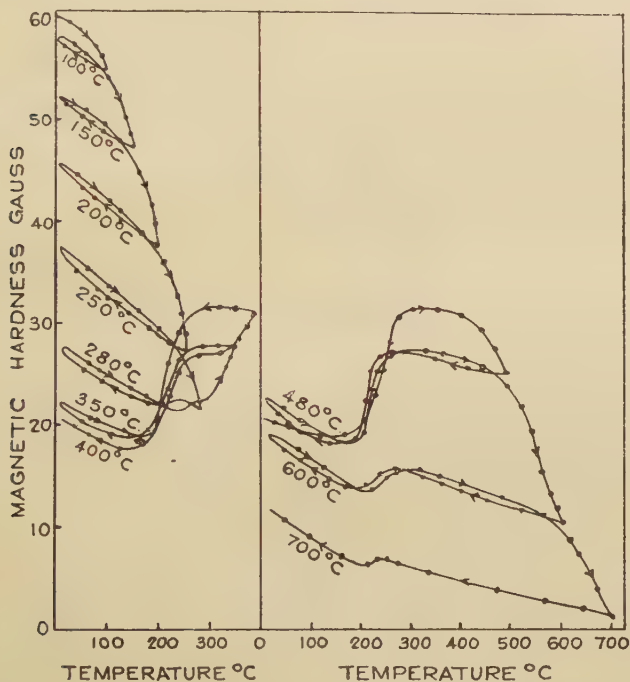


FIG. 8.—Magnetic Hardness of a 1.02% Carbon Steel.

decrease below $400^\circ C.$, according as the double carbide loses or gains its magnetism. It is, therefore, easily understood that the increase of the magnetic hardness between 300° and $400^\circ C.$ in Fig. 6 is due to the formation of cementite, through which reaction a part of the iron is converted into the non-magnetic combined state.

The result of a similar but more extended experiment, in which the heating and cooling were conducted at every 50° to 100° C., is given graphically in Fig. 8. The curves show that notwithstanding that the decomposition of martensite should be complete at 280° C., below that temperature the abnormal rise or fall with the A_0 transformation in the hardness curve during heating and cooling is invisible, and the first small changes of the same curves are observable on tempering at 280° C., showing that below 300° C. the formation of cementite is very small, the greater part of the carbon precipitated being present as free carbon. Between 300° C. and 400° C. the formation of non-magnetic cementite is completed, and hence during heating and cooling a marked rise and fall of the hardness curves are observable in that interval of temperature. Above 400° C., the abnormal change in question is again gradually diminished on account of the growth of cementite particles.

6. QUANTITATIVE MEASUREMENT OF THE A_0 TRANSFORMATION DURING THE TEMPERING OF QUENCHED STEEL.

Magnetic investigations of the A_0 transformation during the tempering of quenched steels have already been made by Honda ⁽¹¹⁾ and Saitô.⁽²⁾ In the present investigation the authors intended to make a quantitative measurement of the abrupt change in the magnetisation due to the A_0 transformation, and they therefore adopted a differential method to magnify the abrupt change in question. A quenched steel of the same carbon content as before was successively tempered at high temperatures, and after keeping it for twenty minutes at the maximum temperatures the cooling curves were taken. The results are shown in Fig. 9; the curves are drawn one above another in order to avoid overlapping.

From these curves it will be observed that below 275° C. the amount of the A_0 transformation is extremely small, but from 300° C. upwards it increases rapidly and attains its maximum value at 400° C. These facts show that just after tempering the carbon is present in the free state, but not as cementite, and that in the temperature interval 300° to 400° C. most of it combines with iron to form cementite. Thus the view proposed by Tammann and Schell is not probable. In the figure it is also

noticeable that a small quantity of cementite is produced even below 300°C . Above 400°C . the magnitude of the A_0 trans-

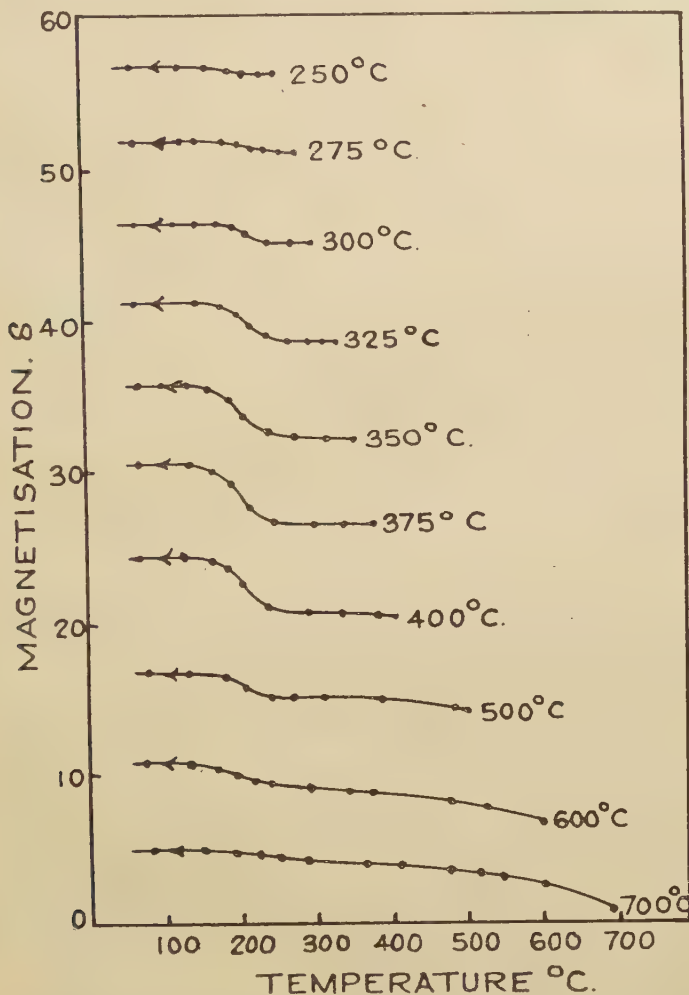


FIG. 9.—Change of the A_0 Transformation (1.02% Carbon Steel)

formation apparently diminishes on account of the growth of cementite particles.

7. MICROSTRUCTURES OF TEMPERED STEELS.

The microstructures of tempered steels are troostite, sorbite, and granular pearlite, depending on the degree of tempering. According to Benedicks,⁽¹²⁾ troostite is a mechanical mixture of iron and cementite finely dispersed as colloidal particles, and sorbite is a structure in which cementite particles in troostite are coagulated so as to form fine microscopic particles. Hence the above-mentioned three structures do not differ in their nature from each other, the difference being only in the degree of coagulation of the cementite particles. But, according to the present investigation, during tempering, at 300° C. carbon is mostly present as free carbon, and at 400° C. it almost completely combines with iron in the form of cementite; hence it is reasonable to define troostite as a structure of a tempered steel, in which the carbon is present as free carbon, and sorbite as a structure in which all the carbon is recombined.

According to this definition, by tempering a quenched steel at different temperatures the structure below 100° C. is pure martensite; above this temperature troostite is gradually formed, and is present in admixture with the martensite. At about 300° C. the structure is pure troostite, and above this temperature sorbite is gradually formed from troostite, the transition being complete at about 400° C. Hence between 300° and 400° C. the structure is a mixture of troostite and sorbite or troosto-sorbite,⁽¹³⁾ becoming pure sorbite at 400° C. The so-called osmondite is identical with this state. Above 400° C. the structure gradually changes from sorbite to granular pearlite. Again, in tempering a quenched carbon steel at gradually increasing temperatures, the internal stresses are released in the range of temperature 450° to 550° C. as a consequence of the recrystallisation of ferrite,⁽¹⁴⁾ and the rapid coagulation of cementite begins to take place in this temperature range.

According to the authors' recent investigation,⁽¹⁵⁾ the solubility of tempered carbon steels in dilute sulphuric acid rapidly decreases when the temperature of tempering lies within that same range, and from 550° C. upwards there is no appreciable change of solubility up to the Ac_1 point, indicating that the coagulation begins to take place at about 450° C. and is almost complete

at 550° C. In Fig. 10 three curves of solubility belonging to three different carbon steels are reproduced for the purpose of reference. Hence it is also very reasonable to place the boundary between sorbite and granular pearlite at about 550° C. for carbon

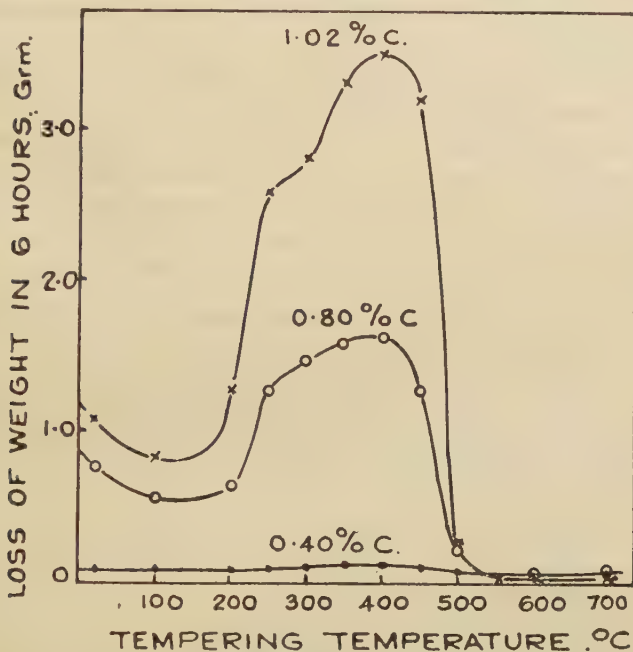


FIG. 10.—Solubility in 1 per Cent. Sulphuric Acid.

steels. Thus, to the authors, the following classification of the tempered structures of quenched carbon steels seems to be scientific and legitimate :

Temperature. °C.	Structure.
100 to 300	Martensite + troostite.
300	Troostite.
300 to 400	Troostite + sorbite.
400	Sorbite (osmondite).
400 to 550	Sorbite + granular pearlite.
550 to Ac ₁ point	Granular pearlite.

It is here to be noticed that the above classification of the structures is, of course, valid for a normal rate of heating. As the rate of heating becomes lower these temperatures are to be lowered.

8. SUMMARY.

The results of the present investigation may be summarised as follows :

1. When quenched carbon steels are heated at a normal rate α -martensite is tempered at 100° to 170° C., and β -martensite at 170° to 300° C.

2. The decomposition product of martensite is free carbon, and not cementite as is usually believed.

3. This precipitated free carbon combines with iron mainly in the temperature range 300° to 400° C. to form cementite.

4. The authors propose boundary temperatures for three tempered structures, that is, troostite, sorbite, and granular pearlite, based on the results of the present investigation.

In conclusion, the authors wish to express their hearty thanks to Professor K. Honda for his valuable advice on the theoretical considerations ; to Dr. S. Watanabe, President of Nippon Tokushukô Goshikaisha, who gave constant encouragement during the course of the investigation ; and also to Mr. N. Watari for making the elaborate measurements of the magnetic hardness.

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A TESTING MACHINE FOR REPEATED IMPACT, AND A PRELIMINARY INVESTIGATION ON THE EFFECTS OF REPEATED IMPACT ON LOWMOOR IRON.¹

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PRELIMINARY STATEMENT.

THE question of the effects of repeated stress, first investigated by Wöhler,² remained dormant for many years, but within the past twenty years there has been a great revival of interest in the subject. One of the main results attained by the more recent investigators has been the simplification of the methods of applying the stress, and of the manner of its variation. It would appear that the rational development will be found in giving attention to simple direct stress and simple harmonic and periodic stress variation. In order to appreciate the extent of the investigatory work of the past twenty years, a careful study should be made of the synopsis of the subject provided by the University of Illinois Bulletin, or "The Fatigue of Metals" by H. J. Gough. Such a study, together with a survey of existing appliances, cannot fail to show that many of these appliances, although probably valuable as workshop machines, are not likely to lead to any true scientific development.

The majority of these machines are of the hammered "rotating beam" type or of the hammered "notched-bar" type, and the interpretation of results is practically impossible owing to the complexity of the resulting stresses. It would appear reasonable, therefore, to aim at the evolution of a machine in which the impulsive stress is applied in the simplest possible manner as

¹ Received April 20, 1927.

² *Engineering*, 1871, vol. xi. pp. 199, 221, 244, 261, 299, 327, 349, 397, 439.

direct stress, thereby eliminating the errors which arise in most ordinary impact testing machines—in particular, to avoid the loss of energy involved in deforming the hammer, the anvil, and the specimen, apart from producing rupture.

The principle involved in the machine described in this paper is not new, Blount, Kirkaldy, and Sankey,¹ and also Professor Hatt² of Purdue University, having already used it. But the object of those investigators was to study the effect of single-blow tests, whereas in the present case the primary object throughout has been to study repeated impact effects—that is, to carry out investigations similar to those carried out by Wöhler, but to use impact instead of a gradual variation of stress.

Our knowledge of impact effects in which the energy is applied in a measurable form may be summarised as follows :

(a) Hopkinson,³ experimenting with long wires, found that the value of the elastic limit is higher when the load is applied by impact than when applied statically.

(b) Sears,⁴ experimenting with colliding rods, verified the results of Hopkinson's work, and found that the elastic moduli are the same for impact tensile tests as for static tensile tests, provided "elastic after-working" is excluded.

(c) Professor Hatt, in describing tests carried out by him, states that the rebound of the hammer after twelve blows was greater than that after one blow. He suggests hardening of the specimen as the cause.

(d) Blount, Kirkaldy, and Sankey evolved a machine on the same principle as that designed by Hatt, in which the energy given to the specimen could be measured independently of any local damage to the anvil, specimen, or hammer. They confined their attention to the important question of simple stress, but only dealt with single-blow effects. Experimenting with various steels, they found that the elongation is about 4 per cent. greater, the percentage reduction in area about 1.5 per cent. greater, and the energy required for rupture about 50 per cent. greater when applied by impact, than the values obtained when the test

¹ *Proceedings of the Institution of Mechanical Engineers*, 1910, p. 715.

² *Engineering*, 1902, vol. lxxiv. p. 28.

³ *Proceedings of the Royal Society*, 1905, vol. lxxiv. p. 498.

⁴ *Engineering*, 1909, vol. lxxxvii. pp. 582, 624.

is performed statically. Moreover, they found that the fracture is of the usual "cone and cup" type, similar to that obtained in the static test.

So far as the authors are aware, no attempt has been made to investigate the effect of tensile or compressive impact when applied repeatedly in such a manner that the energy given to the specimen is known. In the work dealt with below they have endeavoured to reveal the peculiarities of materials when stressed repeatedly by impact.

PRELIMINARY INVESTIGATION AND DESIGN OF NEW MACHINE.

A rough impact machine was constructed for preliminary experimental work. In this apparatus one end of the specimen was screwed into the lower end of a vertical bar 6 ft. long and $1\frac{1}{2}$ in. in diameter. An anvil was attached to the other (lower) end of the specimen. A mass of known weight, free to slide on the bar, was dropped from heights varying from 3 in. to 6 ft. on to the anvil, thus delivering a tensile shock to the specimen. The weight was lifted and released at regular intervals of time.

The apparatus proved useful in finding the connection between the number of blows required to produce rupture and the anvil area, when the falling mass and the height of fall were kept constant. The point is of importance, as this type of machine suffers from the same defect as the majority of impact testing machines in that part of the energy is spent in producing distortion of the falling mass and the anvil.

The machine also served a useful preliminary purpose for a comparison of the energy required for rupture by a "single blow" when dissipation of energy occurs, with that required for a "single blow" when all the energy is absorbed by the specimen.

During the design of the new machine three main requirements were kept in view :

(a) That the energy should be applied to the specimen in such a manner that it could be easily measured, and that there should be no question of indeterminate quantities.

(b) That the energy should be capable of being applied repeatedly, at a constant rate during any test, but that it should be variable for a series of tests.

(c) That the machine should be capable of dealing with specimens of reasonable size.

It is obvious that three great precautions had to be taken :

(a) To ensure that the fall was perfectly free.

(b) To ensure that the whole "dropping mass" was at rest at the top of the lift before being released.

(c) That the mass M (Fig. 1) arrested by the anvil should hit the anvil squarely.

It is evident that if the tup were to strike the side of the anvil, or, even, if the tup failed to strike the anvil, it might still be inclined to the vertical at the instant of impact, and hence, instead of a direct tensile shock being applied to the specimen, there would be a bending effect on the specimen which would render the results valueless.

Since the velocity of impact might be an important point in the investigation, it was decided to make the range of height of fall as large as possible. It was then necessary to devise a mechanism which would enable a mass to be lifted repeatedly to a chosen height. It was decided to use a crank, a multiplying gear, and a wire rope, and to release the "dropping mass" when the crank was at the top end of its throw. To keep the crank within reasonable dimensions a multiplying arrangement was placed between the crank and the mass to be lifted. (See Fig. 1.)

Rotation of the crank C gives a downward motion to the rope attached to the small pulley B , thus causing B and W to rotate and to lift the dropping mass, consisting of M , S , and T . A suitable device releases the mass at the top of the lift. A mass X attached rigidly to the lifting rope now causes both the pulleys W and B to rotate in the opposite direction, when the crank is moving upwards, thus keeping the rope attached to the crank always tight. When the crank reaches the other end of its throw an automatic gripping device grasps the "dropping mass," and hence, on further rotation of the crank, the lifting is commenced again.

The pin projecting from the crank can be adjusted to different radii, thus necessitating an arrangement which would always allow the zero position of lift to be the anvil. This can be accom-

plished by altering the length of one of the ropes. By introducing a turnbuckle *L* into the rope attached to the crank *C* the zero is readily adjusted.

The height of the laboratory allowed a lift of about 8 ft. after

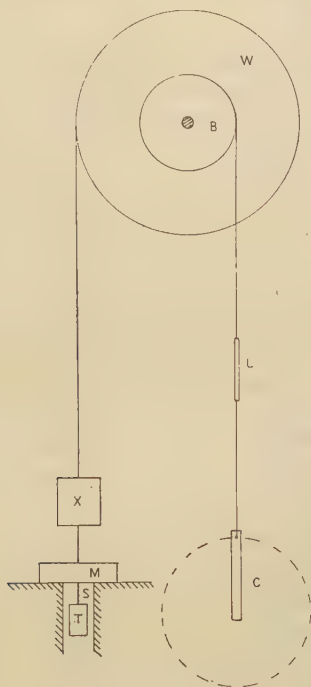


FIG. 1.—Diagrammatic representation of the Principle of the Machine.

allowing 2 ft. 6 in. for the height of the anvil and the same distance for the lifting and releasing devices.

Description of the Machine.—The general arrangement of the machine, as built by Messrs. Greenhill & Craig, Ltd., Belfast, is shown in Fig. 2.

The anvil consists of a cast-iron block, weighing about 14 cwt., resting on a 3-ft. deep concrete base. A hole in the centre allows room for the tup when in its lowest position. This hole opens out to the front so as to afford access for withdrawing the tup or for putting a new specimen into the machine. The

cast-iron block is machined on its upper surface to receive a solid

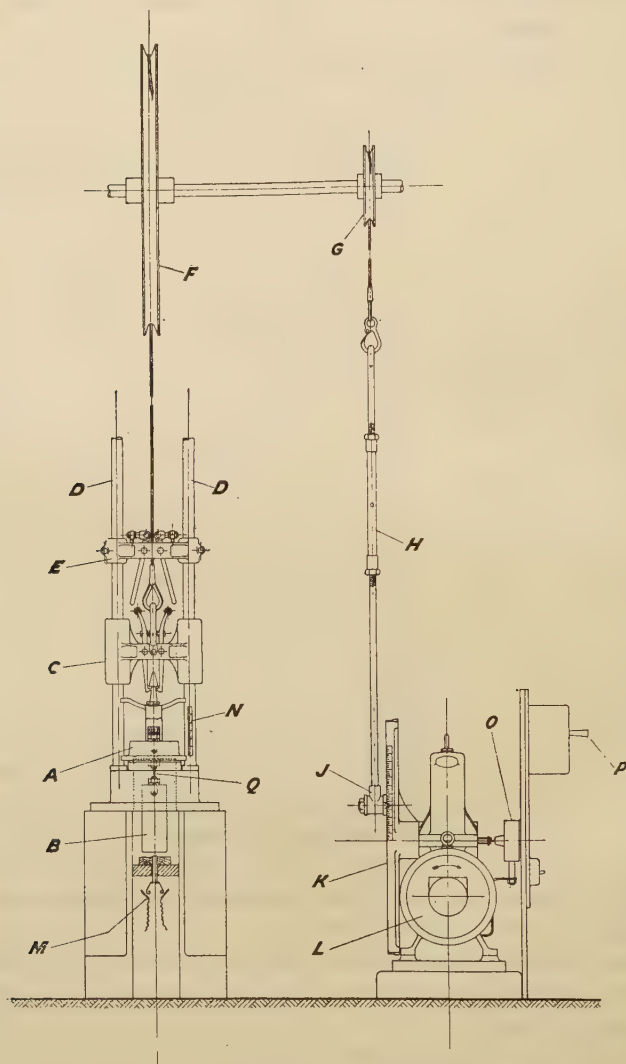


FIG. 2.—The Impact Testing Machine.

forged steel top *Q* of circular form and machined all over. The top is also provided with a central hole to give passage for the tup.

The upper portion of the steel top is in the form of a ring, $6\frac{1}{2}$ in. in external diameter, and $5\frac{1}{2}$ in. in internal diameter, thus giving a striking area of 9.43 sq. in., which is sufficient to prevent undue distortion of the striking surfaces. The striking surface is specially hardened, its average hardness number as found by the hardness comparator being 389.

Two guide rods *D* are bolted to the anvil top, and are held apart at their upper ends by a distance piece provided with a suitable hole to let the lifting rope through.

The arresting cross-head *A* (Fig. 2) is a solid cylindrical forging machined all over. A ring is turned on its base, to form a striking area, which is of the same dimensions as that on the steel anvil top *Q*. The surface in this case is not hardened. A circular flange projects from the sides, in which are cut two recesses for the guide rods. A hole tapped to $\frac{3}{4}$ in. is placed centrally to receive the upper end of the specimen.

Fastened to this cross-head is a forging with cross-arms in which are also cut recesses for the guide rods. The cross-arms and the projecting flange were introduced so that if, for some reason, the triggers got out of adjustment and did not release simultaneously, thus tending to make the tup fall in an inclined position, the guide rods would give the whole mass a slight tip and put the tup into the vertical. The arms were kept at about 6 in. from the top of the cross-head in order to prevent "chattering."

A pin is screwed into the top of this forging, the upper end of the pin being formed into a knife-edge, which opens out the triggers when they come down to raise the "falling mass." In the underside of this knife-edge, and at right angles to its direction, two V-shaped grooves are cut, the lifting surfaces of the triggers being knife-edged to fit these grooves. The "falling mass" when being lifted thus swings on knife-edges and takes up a vertical position in one plane, and by careful adjustment of the triggers and the releasing plates the vertical position is assumed in a plane at right angles to the previous one. Tests made by placing a spirit-level resting on the cross-head, while the lift was taking place, showed that the bubble always kept the central position, no matter in what direction the level was placed. The cross-head and forging weigh about 40 lb., being purposely made heavy in order that any slight frictional effects might be negligible.

The adjustable cross-head *E* supports the releasing plates, which are of steel with hardened faces, and the method by which a very fine adjustment for instantaneous release is possible is shown in Fig. 2.

The speed-reduction gear for hoisting the drop-weight is directly coupled to a direct current shunt-wound motor of 2 H.P. An automatic counter *O* is fixed to the reduction gear, being driven from the shaft carrying the crank. Since one revolution of the crank corresponds to one fall of the masses, the counter records the number of shocks.

An automatic cut-out *M* is provided (Fig. 2). When the specimen breaks, the tup falls on the projecting insulated pin, makes contact, and short-circuits the coil in the starter, thus stopping the motor. A space of 18 in. is left between the anvil and the motor in order that there may be complete freedom of action when working around the machine.

The normal speed of the driving motor is 1000 r.p.m., with a speed-reducing gear of 25 to 1. Thus in normal running, forty blows per minute can be delivered which, for repeated impact, can be used for falls up to 30 in. For falls above this height the number of blows is usually small, and provision is made for driving at a slower speed.

The Specimen.—The shape of the specimen used is shown in Fig. 3. Each end is threaded, and these are screwed into the tup and arresting cross-head to receive a steel ball against which the

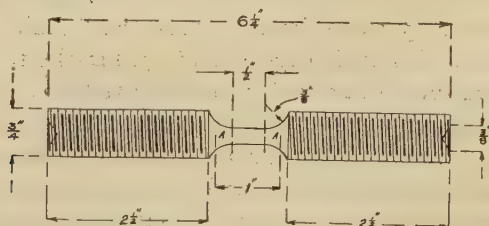


FIG. 3.—The Specimen.

specimen is locked, thus assuring central alignment. In order to measure the extension, centre-pops were placed at *AA*, 1 in. apart.

The tups are of cylindrical form, a suitable hole being bored

centrally at one end, and tapped to receive the specimen. The bottom of the hole is made conical to receive a steel ball.

Adjustment of the Machine to Deliver a Blow of Chosen Energy of Impact, and Method of Placing Specimen in the Machine without Initial Stress.—Suppose it is desired to let the specimen fall through a height x in. It is necessary to allow $\frac{1}{4}$ in. more, so that in the lowest position the lifting triggers are this distance below the bottom of the knife-edge on the arresting cross-head. The spring in the triggers consequently has time to open out and put the triggers into the proper position to lift the “dropping mass.” The height $(x + \frac{1}{4})$ in. is then divided by 7.625 in order to get the crank radius. The crank radius being adjusted, the motor is turned by hand to make the adjustment necessary to bring the zero position of lift to coincide with the top of the anvil. The particular tup that it is desired to use is selected and a steel ball dropped to the conical bottom of the hole which receives the specimen. The specimen is then screwed home and a split spring washer is dropped over it, resting on the top of the tup. A lock nut is then screwed down the specimen on top of the washer and made as tight as possible.

Another nut is then screwed down the upper end of the specimen until it comes loose half-way down the specimen, and a split spring washer is placed on top of the nut. The specimen with tup attached can now be entered into the opening in the cast-iron portion of the anvil. A steel ball is placed on top of it and the whole raised up to the cross-head, and the specimen screwed into the central hole. The spring washer is raised and the nut screwed up the specimen and locked against the under-side of the cross-head.

The tacheometer reading being taken, it is only necessary to see that the cut-out is in proper position. The machine is now ready for starting.

Experiment on the Freedom of Fall of the “Dropping Mass.”—Although clearance had been left and all possible precautions had been taken to secure absolute freedom of fall of the “dropping mass,” it was felt that a free fall was a matter of such vital importance that it was decided to find the value of the acceleration of the “dropping mass” after release.

A board was fastened, in a vertical position, on the arresting

cross-head, and a tuning-fork with a frequency of 30 per sec. was mounted on the steel anvil top. The fork was so arranged that a projecting pin on its free end was just touching a smoked paper fastened to the vertical board. The "dropping mass" was then raised and the fork set in vibration. The mass being released, a curve of the well-known type was produced. The average value of acceleration was found to be 31·37 ft. per sec.², the greatest variation being of the order of 1·5 per cent. The fall was sufficiently free to warrant the neglecting of any frictional effects.

THE MATERIAL USED AND ITS PROPERTIES.

As the principal object of this research was not to study impact effects on a variety of materials, but to make as complete an investigation as possible of the important questions relating to diameters, lengths, cross-sections, variation of corners, notches, &c., it was considered of great importance to get a material of uniform quality rather than to take a variety of materials.

Lowmoor iron was accordingly used. It was obtained in bar form $\frac{7}{8}$ in. in diameter, and was used for the investigation without special treatment. The makers, Messrs. Lowmoor and R. Heath & Co., Yorkshire, guaranteed it all of uniform quality and supplied the following chemical analysis :

	%
Silicon	0·140
Phosphorus	0·136
Sulphur	0·012
Manganese	0·010
Carbon	0·085
Iron	99·617
Total	100·00

The usual static tension tests were carried out on turned bars of uniform size, the overstrain being measured every 500 lb. for a length of 8 in. The extensometer measurements were taken on a length of 10 cm. and were measured for every 250 lb. load added (the load being put on by hand in a very careful manner). The hardness tests were carried out with a 10 mm. ball and a pressure of 3000 kg. The indentation was made in the direction of the length and also in a transverse direction. The hardness number was calculated by dividing the load applied into the area of the impression made by the ball.

The following results are in each case the average of a number of tests :

<i>E</i>	28,470,000 lb. per sq. in.
Yield stress	13·95 tons per sq. in.
Reduction in area	55·85%
Elongation on 8-in. length	29·06%
Brinell hardness number taken along length of bar	109
Brinell hardness number taken on cross-section of bar	121

INVESTIGATION OF THE PROPERTIES OF THE MATERIAL WHEN SUBJECTED TO REPEATED IMPACT.

In order to study the connection between the variable quantities, applied energy per shock, total energy for rupture, extension, reduction of area, velocity of shock, and total number of shocks for rupture, the following procedure was adopted.

A 2-lb. tup was chosen and a specimen broken by repeated shocks, the tup falling through a fixed height. The same tup was then used for a range of fixed heights of fall, and for each fixed height of fall the number of shocks required to rupture a specimen was noted. The range of variation in the total number of shocks was from two or three shocks to about seventeen thousand shocks. For each fixed height the extension and reduction of area were noted. The results of these tests are given in Table I.

It will be observed that as the fixed height of fall diminishes (velocity of shock) both the extension and reduction of area diminish, but at the same time the number of shocks to produce rupture, and consequently the total energy to cause rupture, increase. In Fig. 4 fixed height of fall is shown plotted against the number of shocks to produce rupture, and the resulting curve *A* shows that the connection between these quantities is not of a simple nature; it will also be observed that the curve becomes very flat when the fixed height of fall reaches a value of about 2 in. From repeated impact tests carried out with the preliminary rough machine, the authors suspected that there was a limiting range of impact energy which could be applied repeatedly without causing the specimen to rupture. If, now, each fixed height is multiplied by the weight of the tup, the curve *A* (Fig. 4) also shows the variation in energy per shock with the total shocks required to produce rupture of the specimen. The asymptotic

TABLE I.

Weight of Tup, 2 lb.

Specimen Number.	Height Fallen, Inches.	Velocity of Shock Ft. per sec.	Energy per Shock, In.-lb.	Number of Shocks for Rupture.	Total Energy for Rupture, In.-lb.	Extension on 1-in. Length.	Diameter, Inch.		Percentage Reduction of Area.	Type of Fracture.	Remarks.
							Initial.	Final.			
<i>M</i>	1.95	3.265	3.9	6412	25,000	0.07	0.2505	0.2505	0	Granular	(Slight waist, but fracture next to tup and not at waist)
<i>N</i>	2.25	3.47	4.5	7355	33,100	0.17	0.2505	0.181	52.25	Cone and cup do.	
<i>P</i>	2.55	3.7	5.1	2174	11,100	0.15	0.2495	0.1615	58.1	do.	
<i>O</i>	2.75	3.835	5.5	616	3,390	0.18	0.2505	0.1632	57.3	do.	
<i>I</i>	3.0	4.015	6.0	618	3,709	0.17	0.2500	0.1612	58.3	do.	
<i>J</i>	4.0	4.63	8.0	390	3,120	0.31	0.2505	0.1475	65.2	do.	
<i>H</i>	5.0	5.175	10.0	141	1,410	0.225	0.2505	0.1552	61.6	do.	
<i>G</i>	6.0	5.675	12.0	110	1,320	0.25	0.2505	0.1595	59.3	do.	
<i>K</i>	7.0	6.14	14.0	97	1,358	0.35	0.2500	0.1417	67.7	do.	
<i>Q</i>	15.0	8.98	30.0	28	840	0.25	0.2505	0.1522	63.0	do.	
A50	40.0	14.6	80.0	6	480	0.191	0.2505	0.1655	56.3	do.	

nature of the curve and its similarity to those obtained in fatigue experiments,¹ where the stress varies gradually, tend to confirm

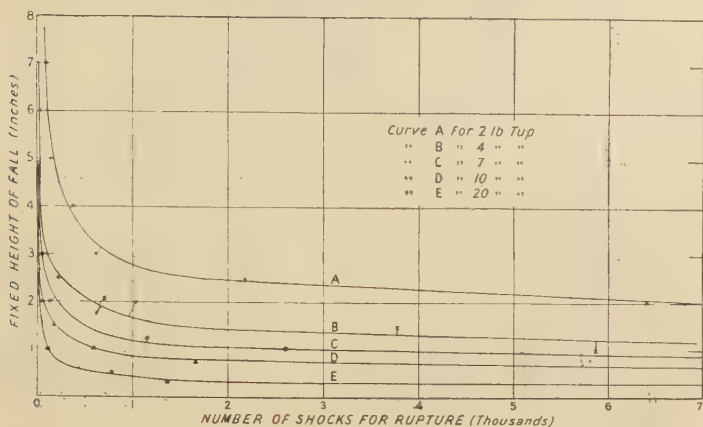


FIG. 4.

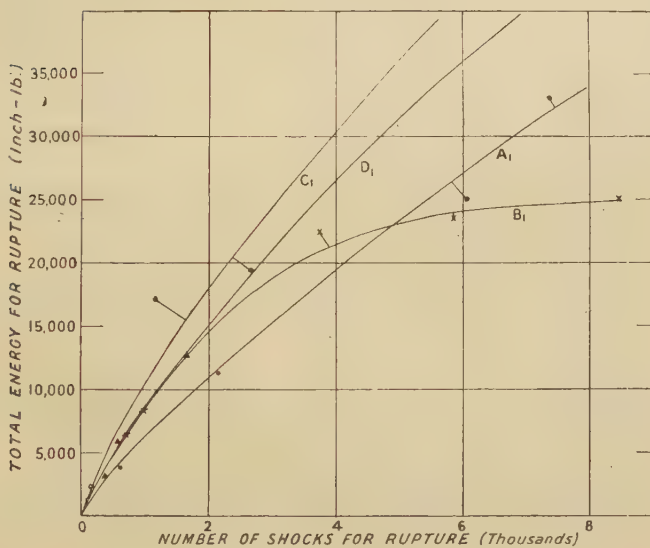


FIG. 5.

the view that there is a limiting range of impact energy, just as

¹ J. H. Smith, "Some Experiments on the Fatigue of Metals," *Journal of the Iron and Steel Institute*, 1910, No. II. p. 246.

TABLE II.
Weight of Tup, 4 lb.

Specimen Number.	Height Fallen. Inches.	Velocity of Shock. Ft. per sec.	Energy per Shock. In.-lb.	Number of Shocks for Rupture.	Total Energy for Rupture. In.-lb.	Extension on 1-in. Length.	Diameter. Inch.		Percentage Reduction of Area.	Type of Fracture.	Remarks.
							Initial.	Final.			
A2	0.75	2.05	3	8434	25,302	0	0.2505	0.2505	0	Granular	In each case fracture occurred at tup end of specimen
Z	1.0	2.315	4	5878	23,512	0.025	0.25	0.25	0	do.	
A1 X	1.5 1.75	2.875 3.065	6 7	3783 550	22,698 3,850	0.01 0.13	0.2505 0.25	0.2505 0.1622	0 57.72	do. Cone and cup	
S	2.0	3.275	8	1038	8,304	0.2	0.25	0.1535	62.2	do.	(After 200 blows periods of no rebound)
V	2.25	3.47	9	702	6,318	0.18	0.2505	0.1555	61.6	do.	(A waist formed next cross-head, then another next tup at which fracture occurred)
U	2.5	3.66	10	217	2,170	0.27	0.25	0.1496	63.9	do.	
T	3	4.015	12	92	1,104	0.18	0.25	0.1535	62.2	do.	
A3	4	4.63	16	81	1,296	0.2	0.2505	0.1596	61.6	do.	
W	6	5.675	24	29	696	0.22	0.2505	0.1575	60.2	do.	
A5	8	6.55	32	24	768	0.21	0.2505	0.1672	55.3	do.	
A4	11.75	8.0	47	13	612	0.215	0.25	0.1613	58.3	do.	
A6	18	9.85	72	8	576	0.20	0.2505	0.1554	61.6	do.	
A7	27	12.0	108	5 (4½)	540	0.20	0.2495	0.1594	59.15	do.	
A40	100	22.8	400	1	400	0.20	0.2505	0.1672	55.3	do.	

TABLE III.
Weight of Tup, 7 lb.

Specimen Number.	Height Fallen. Inches.	Velocity of Shock. Ft. per sec.	Energy per Shock. In.-lb.	Number of Shocks for Rupture.	Total Energy for Rupture. In.-lb.	Extension on 1-in. Length.	Diameter. Inch.		Percentage Reduction of Area.	Type of Fracture.	Remarks.
							Initial.	Final.			
A18	0.75	2.05	5.25	16,963	89,000	0	0.2505	0.2505	0	Granular	{ Fracture at tup end
A16	1.0	2.315	7.0	2,608	19,235	0.13	0.2495	0.1691	54.0	Cone and cup	
A26	1.45	2.86	10.15	1,153	11,730	0.13	0.25	0.1671	55.2	do.	
A15	1.95	3.265	13.65	139	1,900	0.2	0.25	0.1633	57.7	do.	
A10	3	4.015	21	57	1,200	0.22	0.2505	0.1595	59.3	do.	
A19	4	4.63	28	28	784	0.21	0.2505	0.1614	58.3	do.	
A20	5	5.175	35	15	525	0.215	0.25	0.1614	58.2	do.	
A12	6	5.675	42	15	630	0.22	0.25	0.1595	59.2	do.	
A21	9	6.945	63	9	567	0.20	0.2495	0.1634	56.9	do.	
A24	56	...	392	1	392	0.2	0.25	0.1671	55.2	do.	

TABLE IV.
Weight of Tup, 10 lb.

Specimen Number.	Height Fallen, Inches.	Velocity of Shock, Ft. per sec.	Energy per Shock, In.-lb.	Number of Shocks for Rupture.	Total Energy for Rupture, In.-lb.	Extension on 1-in. Length.	Diameter, Inch.		Percentage Reduction of Area.	Type of Fracture.	Remarks.
							Initial.	Final.			
A48	0.5	1.636	5.0	9717	48,585	0.115	0.2505	0.1869	43.3	Granular	{ Fracture at tup end
A47	0.75	2.05	7.5	1673	12,550	0.185	0.2505	0.1712	53.2	Cone and cup	{ Fracture at tup end
A42	1.0	2.315	10	592	5,920	0.135	0.2505	0.201	35.85	do.	
A49	1.3	2.6	13	118	1,530	Unmeasured	0.2505	0.1654	56.3	do.	
A46	1.6	2.9	16	176	2,820	0.24	0.2505	0.1555	61.3	do.	
A43	2	3.275	20	51	1,020	0.21	0.2505	0.1634	57.5	do.	
A44	3	4.015	30	38	1,040	0.214	0.2500	0.1634	57.25	do.	
A45	6	5.675	60	11	660	0.216	0.2505	0.1594	59.3	do.	
A28	40	14.6	400	1	400	0.20	0.2505	0.1634	57.3	do.	

TABLE V.
Weight of Tup, 20 lb.

Specimen Number.	Height of Shock. Ft. per sec.	Energy per Shock. In.-lb.	Number of Shocks for Rupture.	Total Energy for Rupture. In.-lb.	Extension on 1-in. Length.	Diameter. Inch.		Percentage Reduction of Area.	Type of Fracture.	Remarks.
						Initial.	Final.			
A70	0.3	6	1357	8142	0.20	0.25	0.1672	52.8	{ Fracture at second	{ Double - waisted specimen ; fracture at second waist
A69	0.5	10	782	7820	0.20	0.25	0.1672	52.8	do.	do.
A68	1	20	104	2080	0.37	0.25	0.1575	60.2	do.	{ Double waist, with drawing out very marked at each waist
A67	2	40	31	1240	0.30	0.25	0.1487	64.6	Cone and cup	{ Slight sign of double waist
A66	4	80	7	560	0.23	0.25	0.1595	59.2	do.	
A65	5.5	110	5	550	0.26	0.25	0.1575	60.2	do.	
A64	9.75	195	3	585	0.21	0.25	0.155	61.4	do.	
A61	20	400	1	400	0.17	0.25	0.193	40.6	{ Not broken, but large waist formed	
A60	23	460	1	460	0.185	0.25	0.1713	52.2	Cone and cup	Broken

there is a limiting range of stress, which can be applied repeatedly to a specimen without producing rupture. The total energy to cause rupture is shown plotted against the total number of shocks in Fig. 5, and the resulting curve A_1 obtained.

A series of tups was then used and tests of a similar nature carried out, the results of which are given in Tables II., III., IV., and V. Curves showing the connection between the quantities plotted above were drawn and are to be found in Figs. 4 and 5. The curves B , C , D , and E are all of a similar nature to A , and the curves B_1 , C_1 , and D_1 of a similar nature to A_1 .

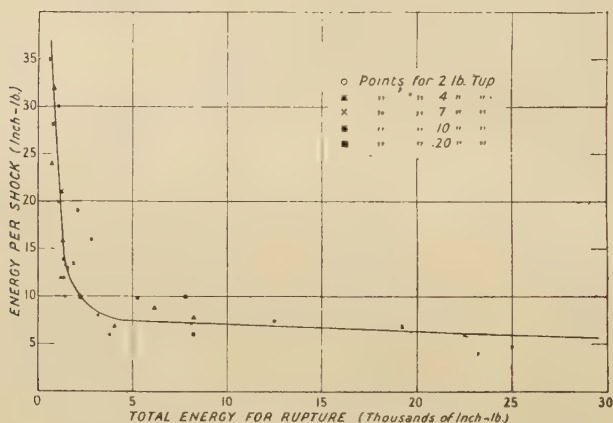


FIG. 6.

In Fig. 6 the energy per shock is shown plotted against total energy for rupture, and it will be noticed that the resulting curve is also of an asymptotic nature, this, of course, being curve A to a different scale. It will be observed, however, that all the points so obtained lie on the new curve drawn. This leads to an interesting conclusion, namely, that if a given amount of shock energy is applied repeatedly to a specimen, then the total energy to rupture the specimen is constant for this amount of single-shock energy; or, in other words, the single-shock energy may be made up of a small mass with a large drop or a large mass with a small drop. This would point to the conclusion that momentum is not the important factor when rupture is considered.

In fatigue tests much laborious work is necessary to obtain

complete information on the values of limiting ranges for all values of range and mean stress. Various investigators have attempted to put the question in mathematical form, which calls to mind the equations of Stromeyer,¹ &c., in which an expression for the limiting range is given in terms for equal and opposite stresses, and other quantities. So far as can be ascertained no development seems to have arisen from such work. In this

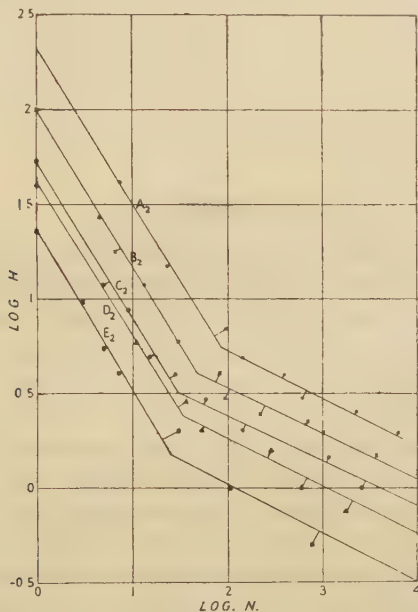


FIG. 7.

preliminary work, however, it is important to search for some simple curve or mathematical expression which will give as a result of three or four tests a whole field of results. As a result of plotting all tests on wrought iron in various ways, the most promising method seems to be that shown in Fig. 7, graphs A_2 , B_2 , C_2 , D_2 , and E_2 . Here $\log. H$ is plotted against $\log. N$, where H represents the fixed height of fall for a particular test, and N represents the number of shocks required to cause rupture at this fixed height. It will be observed that the resulting graph

¹ H. J. Gough, "The Fatigue of Metals."

is a straight line for approximately two hundred shocks, then it continues a straight line, but at a new slope. Also it will be noted that the graphs, representing the tests carried out with all the tups, are parallel. It would seem from these graphs that for the first two hundred shocks a law of the type $H = AN^x$ would give the relationship between H and N , where A and x are constants, x being negative and of the same value for all tups. After two hundred blows the connection between H and N is still of the same type, but with new values of A and x . Basquin¹ and Moore² have noted similar characteristics in the log.-log. graphs of ordinary fatigue experiments. They find, however, that when the change of slope takes place the graph becomes parallel to the axis of log. N .

SINGLE-SHOCK TESTS.

If each of the above graphs be continued to cut the axis of log. H , values of H are obtained which, when multiplied by the weight of the tup used for the particular curve under consideration, give results all of which are equal in value. This value of H is the constant A in the equation $H = AN^x$, mentioned above, for any one curve.

Now this value of log. H is obtained when log. N is zero ; in other words, it would appear that the energy required to rupture a specimen with a single shock is constant. If true, this lends support to the statement that momentum plays an unimportant part in the energy required to rupture a specimen.

In order to find the height at which a specimen would just break with a single shock, the following method was adopted. The energy required to rupture a specimen with a single shock, as obtained by the above method, was divided by the weight of the tup to be used, and this gave a rough indication of the height through which the tup should fall. Tests were then carried out to find a height at which the specimen just failed to rupture, and also the height at which rupture occurred. The average of these heights was taken to be the true height of fall to cause rupture with a single shock, and this height multiplied by the weight of the tup used gave the energy to cause rupture.

¹ *Proceedings of the American Society for Testing Materials*, 1910, vol. x. p. 165.

² *University of Illinois, Bulletin No. 124*, 1910.

Experiments of a similar nature were carried out for a range of tups, and the results of the tests are given in Table VI. The

TABLE VI.

Weight of Tup. Lb.	Height of Fall.		Average Height of Fall. In.	Energy for Single- Shock Rupture. In.-lb.
	Upper Limit. In.	Lower Limit. In.		
4	100	97	98½	394
5	78	76	77	385
6	65	63	64	384
7	56	53	54½	381½
8	49	47	48	384
9	44	42	43	387
10	40	38	39	390
20	23	20	21½	430

Average value of single-shock energy = 392 in.-lb.

difference between the extreme heights for a particular test was never more than 3 in., hence the percentage error which might arise in assuming the average height to be the correct height would be only about 1 or 2 per cent., since the tups used were very light in weight. With heavier tups, of course, the difference between the extreme heights would require to be much smaller, as the percentage error would be increased. In these tests the cut-out was put out of action and a very soft piece of wood placed to receive the tup after rupture of the specimen. The dimensions of the indent in the wood after being struck by the tup compared with those when the tup fell, from rest, from the zero position of lift, gave a rough indication of the residual energy in the tup. The height of fall which caused a specimen to be broken and gave an indent similar to the one described was taken as the upper limit of height.

From an examination of Table VI. it will be observed that the energy for rupture varies from 381½ to 430 in.-lb., the average value being 392 in.-lb. This result, therefore, lends additional proof to the statement that momentum is not an important factor when rupture is considered.

The above-mentioned method of finding the single-shock energy for a specimen is different from that used by Blount, Kirkaldy, and Sankey, in their investigation on a family of steels.

In their method the tup contained a huge amount of energy after the specimen was ruptured, hence it became necessary to measure accurately the velocity of the tup after rupture of the specimen. This was done by an electrical method described in their paper. They found that the energy required to rupture a specimen by a single shock was 50 per cent. greater than that required to rupture a specimen by static means. The authors considered this result of sufficient importance for verification; they therefore tested several of the actual impact specimens by static means. The

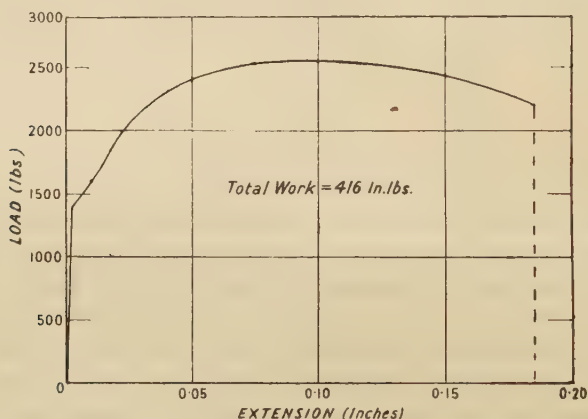


FIG. 8.

extension was measured on a gauge length similar to that used for impact test. The curve shown in Fig. 8 is the average of several tests. The area underneath this curve of course represents the work done in causing rupture, and is found to be 416 in.-lb.

This result gives the ratio $\frac{\text{Single-shock energy}}{\text{Static energy}}$ to be 0.942, and not 1.5 as found by Sankey and his collaborators; while if the value of single-shock energy be taken from the log.-log. graphs the ratio is unity. As the method employed by the authors for finding the single-shock energy did not require the taking of accurate measurements of velocity, and hence did not lend itself to serious error, they are unable to agree with the result obtained by Blount, Kirkaldy, and Sankey. Further, as the two energies are so close, they are of opinion that the amount

of energy required to rupture a specimen by a single shock is equal in value to the energy required to rupture a specimen statically.

Before carrying out the multiple-shock and single-shock tests with the 20-lb. tup, it was found necessary to replace the cross-armed piece on top of the arresting cross-head. The single-shock test was then carried out, and it was found that the energy for rupture had increased to about 600 in.-lb., which would almost give the ratio found by Blount, Kirkaldy, and Sankey.

On investigation, it was concluded that "chattering" had been taking place, and, after some readjustment to ensure the cross-head falling squarely, a new specimen was tried at a height of 23 in. and was ruptured. Another at the height of 20 in. failed to rupture, and the average was taken as the true height for rupture. This gives a single-shock energy of 430 in.-lb., which is not unreasonable.

The new cross-piece was then adjusted for freedom of fall and the repeated-shock test carried out, and the results plotted as previously described. From Fig. 7 it will be seen that the log.-log. curve has the same characteristics as the others. The authors concluded, consequently, that the machine was in proper adjustment.

From the peculiar behaviour of the machine just described it may be supposed that, in the tests carried out by Blount, Kirkaldy, and Sankey, the surfaces were not striking squarely in their machine, and this would account for the large value of single-shock energy which they obtained. The increase of 50 per cent. in the value of the single-shock impact energy, due to inaccuracy of the contact of the striking surfaces, shows that the most careful consideration must be given to the accuracy of the contact of the striking surfaces.

Stanton and Bairstow¹ give the results of a number of single-blow impact tests carried out by them, and they obtain a ratio $\frac{\text{Impact energy}}{\text{Static energy}} = 1.5$. In their machine, however, a great deal of energy is dissipated in distorting the hammer, &c., and they distinctly state that the large value of the ratio is due to this cause.

¹ *Proceedings of the Institution of Mechanical Engineers*, 1908, p. 889.

INVESTIGATION OF THE VARIATION AND GROWTH OF EXTENSION.

From Tables I. to V. it will be observed that the extension is practically nil when a large number of shocks is required to produce

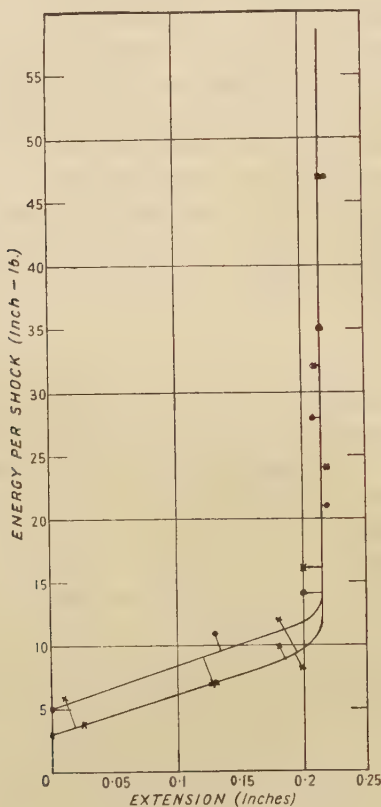


FIG. 9.

rupture, and that the extension appears to increase as the number of shocks decreases, until a certain value is reached at which the extension no longer increases.

In Fig. 9 the energy applied per shock is shown plotted against the total extension when rupture occurs, for the results obtained using the 4-lb. tup. The extension appears to follow a straight line law until it reaches the value 0.215 in., at which it appears to

remain constant. A similar curve is obtained when the results for the 2-lb. tup are plotted. The value 0.215 in. extension is some 4 per cent. higher than that obtained when a specimen is broken statically. These results agree with those of Blount, Kirkaldy, and Sankey, for their single-shock tests. Here, however, not only is it apparently true for single-shock tests, but for repeated tests up to a point at which the repeatedly applied shock energy has a value of about 10 in.-lb.

The reduction of area is about 3 per cent. higher than that when the test is carried out by static means, which result is also in agreement with that of Blount, Kirkaldy, and Sankey.

In order to study the growth of the extension with time, tests were carried out in which the machine was stopped periodically and the extensions noted.

In each test a 7-lb. tup was used, but the height of fall was varied so that the growth could be studied when the number of shocks to produce rupture was large, and also when the number of shocks was small. The greatest time was that when the number of shocks was 1604, and the least time was that when the number of shocks was 122. The results of these tests are to be found in Tables VII., VIII., IX., and X.

TABLE VII.

Fall = 1.5 in.

Diameter of specimen = 0.25 in.

Number of Shocks.	Extension. In.
1	0.02
26	0.04
50	0.04
100	0.04
285	0.05
459	0.09
656	0.14
767	0.20

TABLE VIII.

Fall = 1.3 in.

Diameter of specimen = 0.247 in.

Number of Shocks.	Extension. In.
1	0.0083
25	0.034
50	0.0612
75	0.07
100	0.0812
150	0.0912
200	0.0940
300	0.0945
400	0.104
500	0.104
600	0.110
700	0.111
900	0.121
1200	0.140
1500	0.166
1604	0.201

TABLE IX.

Fall = 1.65 in.
Diameter of specimen = 0.2475 in.

Number of Shocks.	Extension. In.
1	0
5	0.005
10	0.005
15	0.01
20	0.0137
25	0.015
30	0.015
40	0.0275
50	0.035
75	0.045
100	0.066
125	0.088
175	0.101
225	0.171
235	0.191

TABLE X.

Fall = 2.35 in.
Diameter of specimen = 0.248 in.

Number of Shocks.	Extension. In.
1	0.005
5	0.01
10	0.0212
16	0.0375
20	0.04
25	0.045
30	0.06
35	0.0775
40	0.09
50	0.0975
60	0.12
70	0.135
80	0.1462
90	0.164
100	0.175
110	0.194
122	0.215
124	0.215

In Fig. 10 extension is shown plotted against the number of blows for the values recorded in Table VII. Since the shocks are

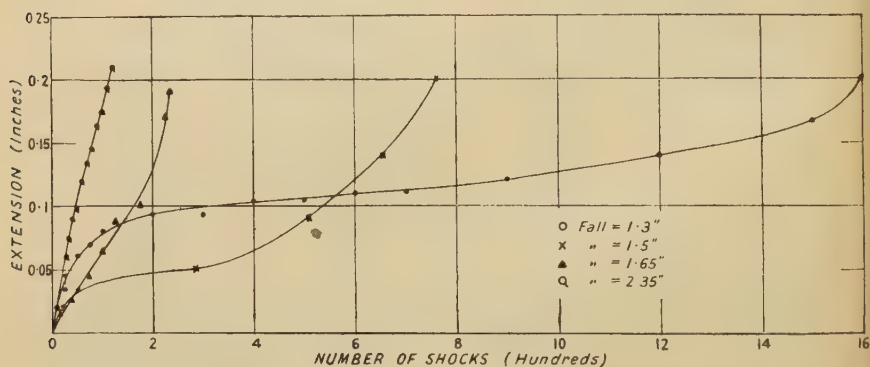


FIG. 10.

being delivered repeatedly at a constant rate, the resulting graph also represents extension and time. It will be observed that the

extension increases rapidly at first, then at a very slow rate; during this time the waist is forming, and finally the extension increases very rapidly until fracture occurs. The values from Tables VIII., IX., and X. are also plotted in Fig. 10 to the same scale as that used for the results contained in Table VII. If, however, the scale of shocks be opened, all the graphs will be found to have the characteristics just described.

The extension measured in this way after shock is the residual extension and not the total extension due to shock. The material is in a state of overstrain, and consequently semi-plastic, therefore the extension due to a shock is larger than the above; but since the material still possesses some elasticity a slight recovery takes place after the effects of the shock have been dissipated, hence the residual extension as measured above is not a true measure of extension due to shock.

In order to show how the extension and diameter vary with the number of shocks to produce rupture, drawings were produced on an enlarged scale of the specimens used in the multiple-shock tests with the 4-lb. tup. The gradual drawing out of the specimens and consequent narrowing at the waist, where fracture occurred, was easily traced from the case where the distortion was practically nil with a fixed height of fall of 0.75 in. to the case where the distortion was very marked with a height of fall of 100 in.

In a number of cases the peculiar phenomenon of two waists forming on a specimen was noted.

EXPERIMENTS ON ROUGH IMPACT MACHINE TO FIND THE EFFECT OF REDUCTION OF AREA OF STRIKING SURFACE.

This experiment was carried out for a twofold purpose. First, to find if possible the variation in the energy required to rupture a specimen with change in area of the striking surfaces, when the height of fall and the falling mass are kept constant. Secondly, to find what area of striking surface should be used for a given falling mass in order that undue distortion of the striking surface might not occur, this point being of importance in the design of the machine used throughout the research. A falling mass of 10 lb. weight was chosen, and it was allowed to fall repeatedly

from a height of 6 in. until fracture occurred. The shocks were delivered at a constant rate of approximately forty per minute. After each test the diameter of the striking surface of the falling mass was reduced, a suitable mass being added on top to keep the total mass constant.

It was found that for areas above approximately 1 sq. in. the amount of energy delivered, to cause rupture, is fairly constant, the average value being 2430 in.-lb. This would appear to show that for all areas above 1 sq. in. the distribution of the total energy between the specimen and the striking surfaces is constant; hence an impact machine having a falling mass of 10 lb. and a striking area above 1 sq. in. would not have the striking surfaces unduly distorted. In the machine used in this research the falling mass was some 30 lb. in weight, and the striking area was made 9.43 sq. in. After working continuously all through this research no distortion of the striking surfaces has taken place.

For areas below 1 sq. in. the total energy delivered increases rapidly, and then appears to decrease. The reason for the increase is that the distribution of energy between the specimen and the striking surfaces has changed, more now going to the distortion of the striking surfaces. A point is then reached at which the surfaces will not stand up to the continual hammering; they become rapidly distorted, hence enlarged, and thus the previous distribution of energy is partially restored.

COMPARISON OF THE ENERGY REQUIRED TO CAUSE RUPTURE WITH EACH MACHINE.

Using a 20-lb. falling mass, it was found in the single-blow tests that a height of 60 in. was required for rupture by a single shock on the rough machine. This gave a single-shock energy of 1200 in.-lb.

From Table V. it will be seen that with the new machine a height of 21.5 in. is required for rupture with a single shock, with the same falling mass, which gives a single-shock energy of 430 in.-lb. The ratio of these is therefore :

$$\frac{\text{Rough machine}}{\text{New machine}} = \frac{1200}{430} = 2.8$$

It has been stated that the average total energy for repeated shocks from a fixed height of fall of 6 in., and using a falling mass of 10 lb., was 2430 in.-lb. From Table IV. it will be observed that with the new machine under the same conditions a total energy of only 660 in.-lb. is required. The ratio for repeated shocks is therefore :

$$\frac{\text{Rough machine}}{\text{New machine}} = \frac{2430}{660} = 3.68$$

These ratios show how abnormal are the results obtained from all impact tests where part of the energy delivered is wasted in distorting the faces of hammers, anvils, &c.

In the repeated-shock tests it is probable that friction and non-accurate hitting of striking surfaces played a greater part than in the single-shock test, which would explain the difference in the ratios.

INVESTIGATION ON THE EFFECT OF THE SHAPE OF THE SPECIMEN ON THE RESISTANCE TO RUPTURE.

In testing any but the most plastic materials statically, it has been observed that when the parallel portion of a specimen is abruptly changed the resultant average stress for rupture is much lower than when the change takes place gradually.¹ Similar effects have been noticed in fatigue testing.² The authors decided to investigate the effect of repeated impact on specimens whose sections varied at different rates. For these tests it was decided to use specimens of larger diameter in order to get a fairly wide range of shocks. The minimum diameter of all specimens was made 0.857 in., which gave a minimum cross-section of 0.1 sq. in. In order to get a comparison of the resistances of the various specimens to rupture it was necessary to adopt a fixed height of fall and a fixed weight of tup for all the tests. • These were made equal to 3 in. and 4 lb. respectively.

¹ D. Morley, "Strength of Materials."

² Stanton and Bairstow, *Proceedings of the Institution of Civil Engineers*, 1905-1906, vol. clxvi. p. 78. Eden, Rose, and Cunningham, *Proceedings of the Institution of Mechanical Engineers*, 1911, p. 839. Moore and Kommers, *University of Illinois, Bulletin No. 124*, 1921.

The investigation was divided into four sections :

- (A) Semicircular grooves of different radii.
- (B) V-grooves of different angles.
- (C) Curved fillets of varying radii with a fixed length of parallel portion.
- (D) Square shoulders with varying lengths of parallel portion.

The results of these tests will be found in Tables XI., XII., XIII., and XIV.

TABLE XI.—*Semicircular Grooves of Different Radii.*

Radius of Groove. In.	Total Shocks for Rupture.	Remarks on Fracture.
$\frac{3}{8}$	1549	Granular fracture
$\frac{1}{4}$	2392	"
$\frac{1}{8}$	2617	"

TABLE XII.—*V-Grooves of Different Angles.*

Angle of Vee. Degrees.	Total Shocks for Rupture.	Remarks on Fracture.
90	326	70% granular, 30% crystalline
60	375	90% " 10% "
52	373	90% " 10% "
45	478	60% " 40% "
30	368	60% " 40% "

TABLE XIII.—*Curved Fillets of Various Radii, with a Fixed Length of Parallel Portion of $\frac{1}{2}$ In.*

Radius of Fillet. In.	Total Shocks for Rupture.	Remarks on Fracture.
$\frac{3}{8}$	1714	Fracture at waist at centre
$\frac{1}{4}$	1370	"
$\frac{1}{8}$	1542	"

TABLE XIV.—*Square Shoulders, with Varying Lengths of Parallel Portion.*

Length of Parallel Portion. In.	Total Shocks for Rupture.	Remarks.
$\frac{1}{32}$	442	Wedge-shaped piece pulled out of centre of section
$\frac{1}{16}$	460	Granular fracture at upper neck
$\frac{1}{8}$	760	Circumferential crack at each neck. Diagonal fracture
$\frac{1}{4}$	868	Circumferential crack at upper neck. Fracture at lower neck
$\frac{3}{8}$	785	Fracture at waist at middle of parallel portion. Circumferential crack at top and bottom shoulder
$\frac{1}{2}$	1710	Circumferential crack at upper neck. Fracture at lower neck
$\frac{5}{8}$	1578	Do. Do.
$\frac{3}{4}$	1420	Do. Do.
1	1531	Slight fracture at top and bottom. Fracture at lower neck and partial fracture at upper neck

An examination of these tables reveals several important facts. First, from Table XII. it will be observed that an average of some 384 shocks is required to rupture a specimen with a sharp V-groove; if, on the other hand, the groove is semicircular, then from Table XI. it will be observed that some 2153 shocks are required to produce rupture. These results confirm the importance of having a well-rounded fillet in any machine part in which a change of section occurs.

A further examination of Tables XI., XII., and XIII. reveals the following points: First, that apparently the number of shocks to produce rupture does not depend on the angle of the V-groove; secondly, that the number of shocks is independent of the radius of the fillet when the length of parallel portion is constant; thirdly, that the radius of a groove has very little effect on the resistance to rupture. The authors are of opinion that the ductility of the material was too great to reveal any difference in the endurance in each of the cases just mentioned, but that with a material such as hard steel great differences would, no doubt, be revealed.

An examination of Table XIV. shows that, when square shoulders are adopted for the change of section, the endurance

is not constant for different values of length of parallel portion. The endurance appears to increase with the length up to a given length, after which it appears to remain constant. The fracture is localised at a shoulder and takes place at the shoulder next the tup, a circumferential crack being observed at the upper shoulder. The only abnormal case in this test is that of the specimen $\frac{3}{8}$ in. in length, the fracture in this case occurring at a waist which formed at the middle of the specimen; a circumferential crack was observed, however, at each shoulder. The resistance was lower than that of the specimen whose parallel portion was only $\frac{1}{4}$ in. long. The authors repeated the test on a new specimen $\frac{3}{8}$ in. long and obtained a similar result. They are of opinion, therefore, that in all probability an investigation on the effect of the ratio $\frac{\text{length}}{\text{diameter}}$ would reveal important results.

THE EFFECT OF SURFACE FINISH ON THE ENDURANCE.

Various experimenters have found that in ordinary fatigue tests the surface finish has an effect on the endurance.¹ The authors decided to investigate this point on the resistance to impact. Specimens of the standard dimensions were prepared with different degrees of finish. The results of the tests showed, however, that apparently the surface finish had very little effect on the endurance of the specimens.

CONCLUSIONS.

1. There is a limiting range of tensile impact energy that may be applied repeatedly to a material without causing rupture.
2. For a given amount of repeatedly applied tensile shock energy, the total energy to rupture a material is constant.
3. Momentum is not an important factor in causing rupture by tensile impact.
4. For a given mass of tup the height of fall and the number of shocks to produce rupture are connected by an equation of the form $H = AN^{-x}$ for a portion of the range, after which a similar law holds, but with a new value of x .

¹ Moore and Kommers, *University of Illinois, Bulletin No. 124*, 1921.

5. The energy required to cause rupture by a single tensile shock is equal to the energy required to cause rupture when static means are employed.

6. When the shocks to produce rupture are below a certain value the elongation is constant and 4 per cent. greater, and the reduction in area is constant and 3 per cent. greater, than when static means are employed.

7. In repeated tensile impact, elongation does not increase at a uniform rate, being more rapid at the beginning and end of the test than at mid-test.

8. In tensile impact machines where energy is dissipated in hammers, anvils, &c., the amount of dissipated energy is constant when the area of striking surfaces is above a given value, provided the height of fall of the hammer is constant. Also, the total energy to cause rupture is approximately three times greater with such machines than with a machine in which no energy is dissipated.

9. Abrupt changes of section, such as that caused by a sharp V-groove, are a serious source of weakness in machine parts that have to withstand repeated tensile impact.

10. The length of a specimen is of importance when square shoulders are used to change the section, the endurance increasing with the length up to a given value, after which it remains constant.

11. Surface finish has little effect on the resistance of a specimen of ductile material to withstand repeated tensile impact.

CORRESPONDENCE.

Mr. S. J. ASTBURY (Dudley) wrote: Professor Smith and Mr. Warnock have presented a very valuable paper for the consideration of the Institute, the results of which must be taken into account by all workers on the problems of fatigue testing. The care with which they have considered and eliminated the various secondary factors which come into play in fatigue testing, such as deformation of the anvil, inaccurate hitting of the striking surfaces, and vibration of the machine, is reflected in the consistency of the results obtained. I cannot help thinking, however, that their observation on p. 354 that "an investigation on the effect of the ratio $\frac{\text{length}}{\text{diameter}}$ would reveal important results" should have suggested itself at the commencement of the experiments rather than at the end. Considerable variations in the fatigue strength would be found following variations in this ratio, even when square-shouldered specimens were not used. Subsequent work on the comparative fatigue strengths of different irons or steels must employ a test-piece of identical dimensions to be of value, and the smallness of this test-piece would be likely to lead to irregular results in the case of harder materials.

The conclusions summarised at the end of the paper are true only of wrought iron. They should not be regarded as of general application to steels—steel being a fundamentally different metal which does not possess to the same degree as wrought iron the power of recovery from overstrain.

It is perhaps unfortunate that the word "Lowmoor" has been incorporated in the title of the paper, as of course the word is used for one proprietary brand of best Yorkshire iron. Wrought iron of this standard, complying with the requirements of the British Standard Specification No. 51, is, of course, made in other parts of the country.

In reply the AUTHORS thanked Mr. Astbury for his remarks; when an investigation had been completed it was always possible for the experimenters to see how they could have done the work better. The experiments recorded in the paper were, they hoped, only a preliminary to something of a more extensive nature, and they assured him that the points he had raised would not be overlooked.

The short specimen $\frac{1}{2}$ in. long and $\frac{1}{4}$ in. in diameter was the standard test-piece for all their fatigue and impact experiments, and in any case, if dimensions were changed, they would proceed very carefully from that form. With regard to his remarks on steel and iron, they were only concerned with material which would give them regular results, and not with any differentiation between iron and steel. The material that they particularly required in their subsequent work was one of absolutely uniform quality.

ON THE QUANTITATIVE MEASUREMENT OF THE CUTTING POWER OF CUTLERY.¹

BY KOTARÔ HONDA AND KINNOSKE TAKAHASI (JAPAN).

1. INTRODUCTION.

UP to the present, the cutting power or sharpness of cutlery has been only qualitatively estimated. For example, it is usual to test the sharpness of a razor on the hair, or that of a knife with the finger. For the scientific investigation of cutlery, an apparatus must first be constructed by which the sharpness may be measured quantitatively; but such an apparatus has not hitherto been invented. Recently, Heikichi Aoyama and Sirô Ishida² tested the cutting power of Japanese swords by means of a machine of the Izod type, using oiled clay as the material to be cut.

Professor H. Iwaoka of the Imperial University of Fukuoka constructed a special apparatus for the same purpose, the principle of which is as follows: He stretches a thread horizontally, and the cutting edge of a cutting implement is brought in contact with the thread from above it. The pressure on the thread is then continuously increased until it is severed. The reciprocal of this limiting pressure is taken as the sharpness of the implement. In actual use, it is usual to apply not only a pressure but also a pull on the cutting edge of the implement, and hence the results of the above methods of testing do not exactly represent the cutting quality which it is wished to measure.

The authors have therefore constructed a simple instrument, and have investigated the sharpness of different implements, and also of old Japanese swords, which are now considered one of the highest works of art in their country. They also investigated the effect of special elements on the sharpness of blades. The following pages contain a description of their instrument and the results of their investigation.

¹ Received April 6, 1927.

² *Tetsu to Kô*, 1924, vol. x. p. 660.

2. SHARPNESS TESTER.

The principle of the new tester¹ is as follows : The cutting edge of the implement is brought into contact, under a definite pressure, with a narrow band composed of sheets of paper about an inch in thickness, and a definite amount of forward and backward motion is given to the implement. The number of sheets

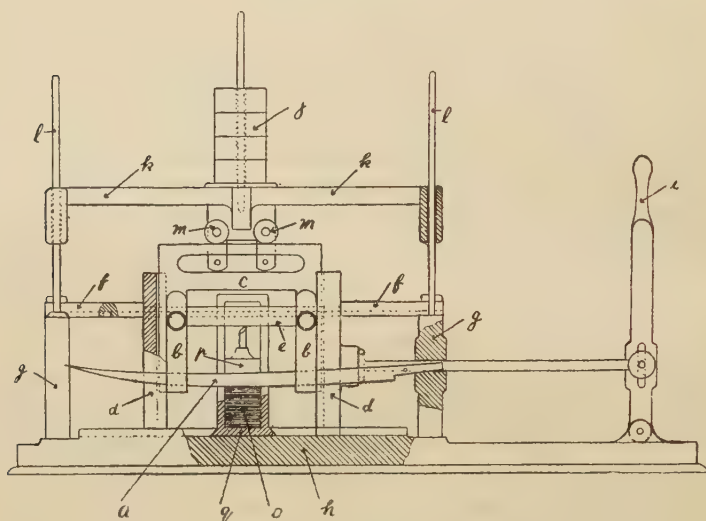


FIG. 1.

cut during this motion is taken as a measure of the sharpness of the implement. Fig. 1 shows the side view of the apparatus.

The blade *a* to be tested is fixed to two arms of a U-shaped frame *c* by means of two fixing blocks *bb*. This frame can slide freely up and down along another frame *dd*, which is fixed rigidly to the horizontal rods *ff* and slides along a groove on the base *h*. The motion of these rods is guided through the horizontal holes in the vertical pillars *gg*. The frame *dd* can be moved backwards and forwards by a handle *i*. *O* is a band of sheets of paper, 1 cm. wide and 20 cm. long, containing several hundred sheets, and which can be passed forward when it is cut through. A hori-

¹ A patent has been applied for in the United States of America and in several European countries.

zontal beam kk carries a weight j , and this beam can move up and down freely, being guided by two vertical pillars ll . By means of two rollers, mm , it exerts a constant pressure on the band of paper.

Since a slight inclination of the blade edge to the horizontal affects the cutting power of the blade more or less, the blade is always moved backwards and forwards to eliminate this source of error. The cutting power has only a relative meaning, and hence for the accuracy of the experiment it is only necessary to use the same kind of paper. In the present case, the backward or forward motion is limited to 2 cm.

Two important factors of a cutting implement are its initial sharpness and its durability. By this apparatus both the initial sharpness and the durability can be accurately measured by the following methods. After the initial sharpness has been measured, the forward and backward motions of the blade are repeated eight times without counting the number of sheets cut, and then a new measurement is made, this giving the sharpness at the 10th cut. Similarly, the sharpness at the 20th, 30th . . . up to the 100th cut are also measured. The curve for sharpness plotted against the number of cuts shows a rapid decrease of sharpness; it is a logarithmic curve. The number of cuts required to reduce the initial sharpness to half its value is defined as the "life" or the "durability" of the cutlery.

TABLE I.—*Relation between Pressure and Cutting Power.*

Pressure. Grm.	Cutting Power.
750	6
1110	10
1400	16
1700	21
2000	28
2300	36
2600	42
2900	55
3100	64
3600	92

The cutting power of an implement depends on the pressure applied on it; hence it was first of all necessary to find out

the relation between the cutting power and the pressure. For this purpose, a razor was used after 100 cuts had been made, because the sharpness of a razor is not sensibly decreased in this way by a few additional tests. The results of measurements are given in Table I. and in Fig. 2.

Thus in the range of pressures 400 to 3600 grm., the cutting power increases at first linearly and then somewhat rapidly, as

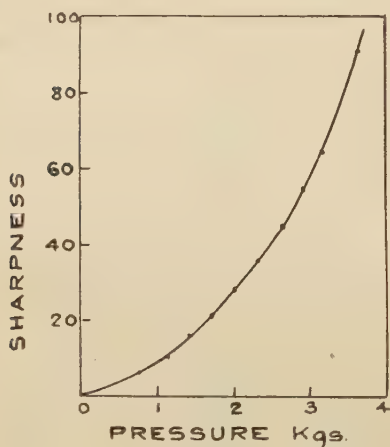


FIG. 2.

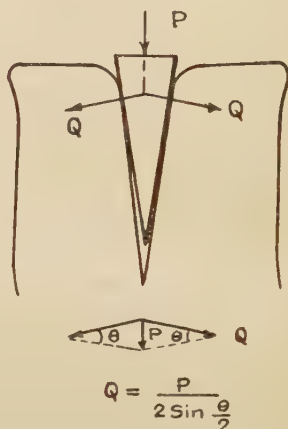


FIG. 3.

the pressure increases. In the actual test for sharpness the total pressure, including the weight of the implement, was always taken as 1.5 kg.

3. THEORY OF THE CUTTING PROCESS.

In the case of Professor Iwaoka's apparatus described in the first section, the cutting is caused by pressure only. Hence the mechanism of cutting is the same as in the case of a wedge. Let P in Fig. 3 be the force applied to a wedge, the angle of which is θ ; then the force Q acting on a body to be cut by the wedge is, as is well known, given by

$$Q = \frac{P}{2 \sin \frac{\theta}{2}}$$

Hence in the case of cutting by pressure, the smaller the edge angle of the blade the greater its cutting power. The authors tested this relation experimentally by making the blades with different edge angles ranging from 12° to 45° from a carbon steel containing 0.9 per cent. of carbon, the quenching and other heat treatments being the same for these blades. The results of experiments are given in Table II. and in Fig. 4.

TABLE II.—*Relation between the Blade Edge Angle and the Cutting Power under Pressure.*

Edge Angle. Degrees.	$Q \times 4.$	"Pressure" Cutting Power.
10	23.0	...
12	18.4	19.6
16	14.4	14.6
24	9.6	10.0
30	7.7	7.8
44	5.3	5.6

The full line in the figure shows the theoretical curve ($4Q, \theta$), and the crosses the observed points. Thus it is seen that the theoretical and experimental curves vary in proportion to each other, the factor of proportionality being nearly 4 in this case. Hence it may be concluded that, when cutting by pressure, the cutting power depends solely on the wedge action.

When cutting by "pull and pressure," the case is rather different. Generally, an implement cuts very much better as the result of pull and pressure than of pressure only. That is, if a blade be laid on a substance and pressure applied, the blade cuts the substance to a certain depth and remains there in equilibrium; but if a pull be applied, it cuts to a further depth and remains again in equilibrium. In the same way, another pull gives a further cut, and so forth. The above mechanism of cutting is explained as follows: As is shown in Fig. 5 on an exaggerated scale, the edge of a blade under a high-power microscope appears to have a form like the teeth of a saw. If a pressure be applied to the blade when in contact with a substance, it cuts the substance to a certain depth and no more; the pressure is then in equilibrium with the reaction acting on the blade edge

from beneath and the friction on the side of it. If the blade be pulled horizontally, the supporting material under it is crushed

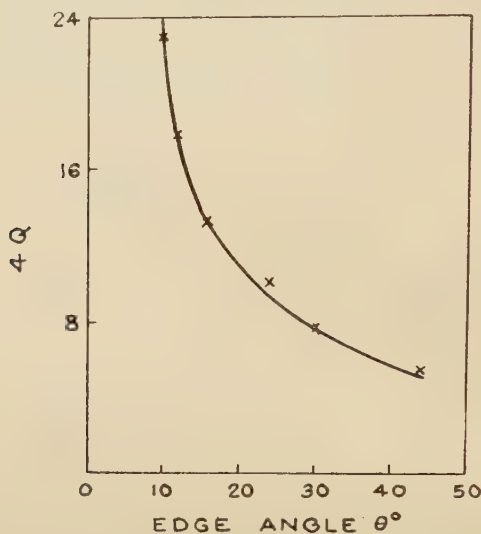


FIG. 4.

and its strength weakened, so that the blade goes down a step further owing to the pressure, until it is again in equilibrium

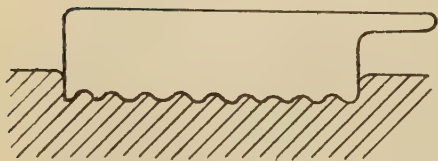


FIG. 5.

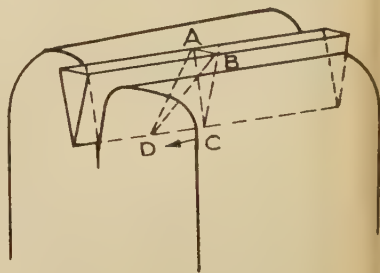


FIG. 6.

under the same forces. In the same way, if the blade be pulled further, it cuts to a further depth, and so on.

The ordinary explanation of the cutting of a blade under a pressure and a pull is as follows :

In Fig. 6, let angle ACB be the edge angle of a blade, and let DC be the amount of pull while cutting through a distance

TABLE III.—*Relation between the Blade Edge Angle and the Cutting Power under Pressure and Pull.*

Edge Angle. Degrees.	"Pull and Pressure" Cutting Power.	
	Razor. A.	Kitchen Knife. B.
12	127	110
17	99	88
20	95	73
27	65	48
30	56	44
38	39	29
45	32	25

BC ; then angle ADB corresponds to the virtual edge angle, which is certainly less than the actual angle ACB . Since the

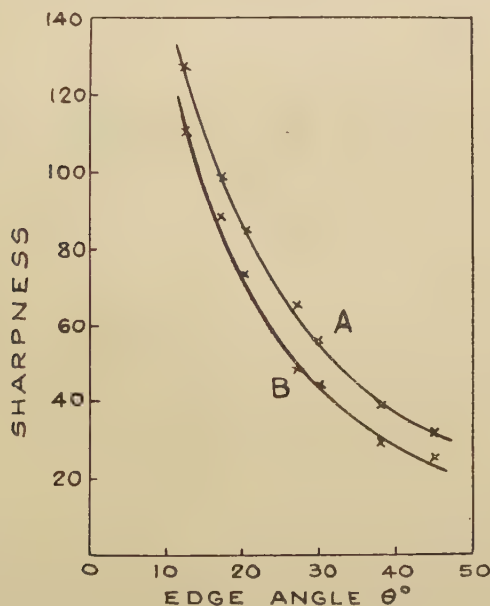


FIG. 7.

cutting power depends on the edge angle, it follows that a pull and pressure cause a greater cut than the pressure only. This explanation is not, however, valid, as is shown by the following. Consider two different cases in which the pull is the same, but the cut in one case is greater than in the other ; then the greater cut is seen to correspond to the greater edge angle of the blade, which contradicts the observed facts.

As in the case of cutting by pressure, the authors also studied experimentally the relation between the cutting power under pressure and pull and the edge angle. The results are shown in Table III. and in Fig. 7. Curve *A* was obtained with a razor, and curve *B* with a kitchen knife. It will be noticed that the form of these curves is decidedly different from that of the curve obtained by cutting under pressure only, and that the cutting power increases rapidly as the edge angle decreases.

4. DETERMINATION OF THE EDGE ANGLE OF A BLADE.

As shown in the foregoing section, the cutting power of a blade increases very rapidly with the diminution of its edge angle. Hence to compare the sharpness of different implements it is necessary to find their edge angle. To measure this angle the blade is lightly pressed on a piece of lead, and then removed ; the lead is then cut normally to the impression of the blade with a sharp knife. This normal section is then viewed at a high magnification under a microscope, which is provided with a copying attachment, and the image of the edge angle is traced on a paper placed on the side of the table by means of a rule. The angle of this drawing is afterwards measured by a simple goniometer, and thus the edge angle can easily be measured. The magnification of the microscope used was usually 400. The sectional profile of a blade is made by casting Wood's metal round the portion of the blade to be examined, and then making a section of the metal transverse to the blade. This section is afterwards photographed with a threefold magnification.

Photographs 16 and 17 (Plate XXIII.) show the sections of a Japanese sword and of a razor. Micrographs 18 to 21 show the blade edges of these implements both before and after 100 cuts. A comparison of these micrographs shows how much these edges were worn by 100 cuts of the sheets of paper. Micrographs

22 and 23 (Plate XXIV.) are those of a razor blade as seen from below, before and after 100 cuts respectively.

5. SHARPNESS OF IMPLEMENTS AND THEIR DURABILITY.

The implements were first polished on grindstones by Mr. K. Satô, a sword technologist in Sendai, and then by a microtom polishing machine designed by Professor H. Iwaoka of the Imperial University of Fukuoka. The edge was then examined under a microscope, and if it was not satisfactory the blade was repolished till its edge became approximately straight, as seen under the microscope. Since the values obtained for each test of sharpness deviated 4 to 5 per cent. from each other, the mean of three independent observations was generally taken as the final result.

Different implements and old Japanese swords were subjected to the test; the results are given in Table IV. and in Fig. 8.

TABLE IV.—*Sharpness of Various Blades.*

Implement.	Sharpness at Various Stages.						Dura- bility.	Edge Angle. Degrees.
	1st Cut.	3rd Cut.	10th Cut.	20th Cut.	50th Cut.	100th Cut.		
Razor (Hänckel) .	117	65	45	36	25	20	8	15
Razor ("Peace")	110	70	44	34	21	14	6	15
Microtom blade .	97	61	48	41	27	17	10	20
Valet razor .	85	36	23	17	10	11	3.5	14
Stainless Hôchô blade .	56	44	27	23	15	10	9	27
Hôchô blade .	55	46	30	22	16	13	12	25
...	31	25	13	12	11	8	7	30
Japanese swords :								
Hiromitsu .	84	46	25	14	9	8	5	25
Masamuné .	66	44	36	20	15	12	15	33
Akihiro .	60	34	20	15	13	11	6	42
Tadatsuna .	58	40	23	20	15	10	8	32
Muramasa .	57	38	21	20	9	8	8	31
Naotané .	52	30	12	9	7	6	4	28
Tadakuni .	42	26	19	15	11	8	7	27
Kunikané .	39	23	14	9	6	4	5	30
Nagamitsu .	32	23	16	11	6	5	7	32
Kanenori .	30	18	14	10	8	5	6	28

From the curves in the figure, it will be seen that the sharpness decreases very rapidly with the number of repeated cuts, and in fact decreases logarithmically.

This form of the "decay" curves of sharpness can also be deduced theoretically. Let N be the number of sheets cut, that

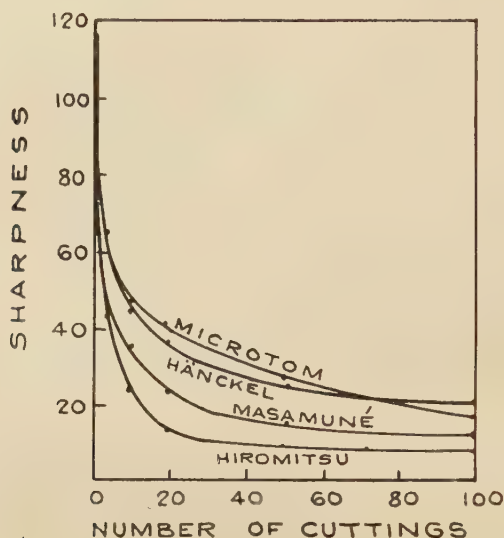


Fig. 8.

is, the sharpness of the blade, and n the number of repeated cuts. Since the decrease of sharpness should be proportional to the number of sheets cut, the relation may be expressed thus:

$$dN \propto Ndn$$

or

$$dN = -kNdn,$$

k being a constant. Then :

$$\frac{dN}{N} = -kdn.$$

Integrating this relation :

$$\text{Log. } N = -kn + \log. C,$$

C being an integrating constant. If N_0 be the initial sharpness, then :

$$n = 0, \text{ and } C = N_0$$

and

$$N = N_0 e^{-kn}$$

Thus the sharpness decreases logarithmically with the number of cuts. N_0 and k depend on the nature of the paper as well as on that of the blade. N_0 depends also on the pressure applied to the blade.

Among the implements here examined, a razor made by Hänckel, in Germany, had the greatest sharpness, and a home-made razor ("Peace") came next; then a microtom, a safety-

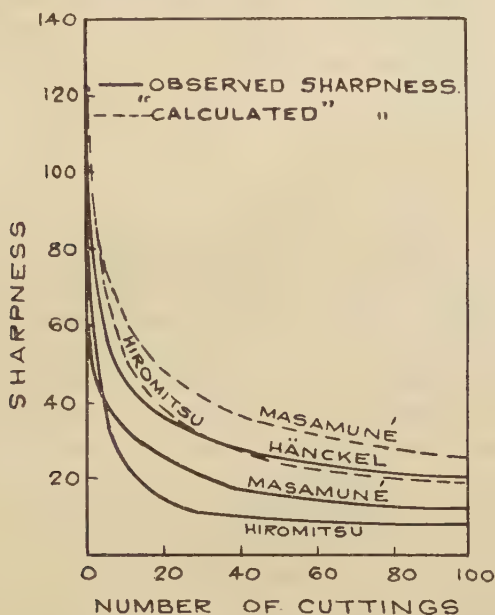


FIG. 9.

razor blade, a Japanese stainless kitchen knife, an ordinary kitchen knife, &c., followed. The fact that the sharpness of the microtom was much inferior to that of the razor was obviously due to the large edge angle (20°) as compared with that of the razor (15°). If the sharpness of the former implement be calculated to correspond to an edge angle of 15° by means of the curve in Fig. 7 it increases to 120. Its greater value of "life" or durability (10) was also due to the same cause.

The best old Japanese sword here investigated was a Masamuné, though its initial sharpness was inferior to that of a

Hiromitsu. This was obviously due to the difference in the edge angles of these swords. It is a remarkable fact that the durability of a Masamuné is very great as compared with that of the others, its life being 15. If the cutting powers of Masamuné and Hiromitsu be calculated to correspond to an edge angle of 15° by means of the curve in Fig. 7 and compared to that of a Hānckel razor, the curves in Fig. 9 are obtained. Though this calculation may not be exactly correct, the figure shows that the Masamuné curve lies higher than the Hānckel and far above the Hiromitsu. This represents the highest achievement in the technique of sword-making in old Japan some six hundred years ago.

6. SHARPNESS OF NEW BLADES.

As shown above, the sharpness of implements and swords already made, which depended on different factors, such as carbon content, quenching temperature, edge angles, &c., was measured. Hence it is very difficult to compare the sharpness of different implements exactly. The authors therefore prepared many blades of the form shown in Fig. 10 from steels of different carbon content and from other steels containing chromium, tungsten, and molybdenum, and they investigated the effects of these elements on the sharpness of these blades.

In order to avoid the oxidation of the blades during the heating for quenching, a lead bath was used; the blade was heated at the required temperature in the bath for thirty minutes, and was then quenched in water. It was then tempered in a mercury bath at a suitable temperature for twenty minutes, and then polished with grindstones, and afterwards finished by the Iwaoka grinding machine to an edge angle of 14° . The blade thus polished was examined under a microscope. Micrographs 24 and 25 (Plate XXIV.) show the edge of the blade before and after the final polishing. If the polishing was not satisfactory and the blade edge was found to be undulatory, the polishing was repeated.

(a) *Sharpness and Carbon Content.*—In the case of pure iron-carbon alloys, there are three important factors which affect the cutting power of a blade—namely, the carbon content and the quenching and tempering temperatures. While keeping two of these factors constant, the effect of the remaining factor was,

investigated. By a preliminary experiment, it was found that the most favourable carbon content for high cutting power was 1 to 1.4 per cent., and that the best quenching and tempering temperatures were respectively 720° to 780° C. and 120° to 200° C. Hence in order to find the best content for carbon, many blades

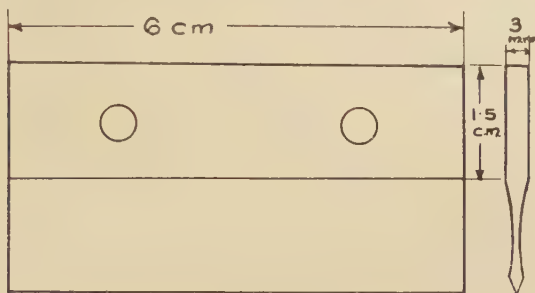


FIG. 10.

of carbon steel containing different amounts of carbon ranging from 0.5 to 1.5 per cent. were prepared, and the quenching and tempering temperatures were made 740° C. and 150° C. respectively. The edge angle of these blades was always 14° .

The results of experiments are given in Table V. and in Fig. 11.

TABLE V.—*Effect of Carbon Content on the Sharpness of Carbon Steel Blades.*

Carbon Content. %	Sharpness.						Durability.
	1st Cut.	3rd Cut.	10th Cut.	20th Cut.	50th Cut.	100th Cut.	
0.5	58	43	27	18	11	7	9
0.9	102	80	56	39	28	17	12
1.1	122	90	63	52	32	19	11
1.3	127	94	68	55	35	20	13
1.5	95	70	56	32	32	20	20

The initial sharpness and the durability are greatest in a blade containing about 1.3 per cent. of carbon. Blades containing more than 1.5 per cent. of carbon were too brittle for a satisfactory edge to be obtained by polishing. Hence it may be

concluded that a content of 1.3 per cent. carbon is the best for a blade.

(b) *Sharpness and Quenching Temperature.*—The test was made for blades of carbon steels containing 0.9 and 1.3 per cent., the

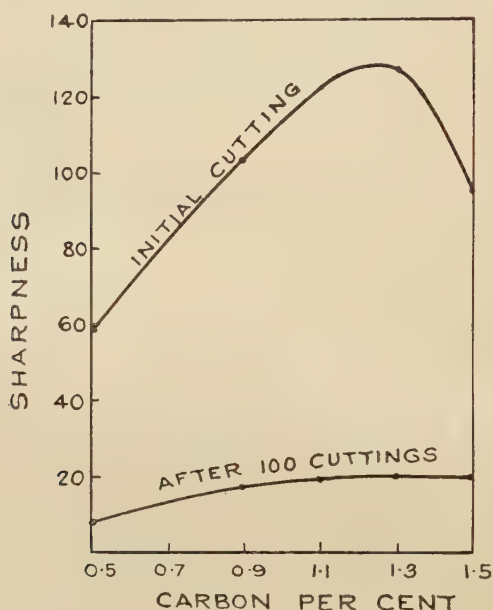


FIG. 11.

edge angle being 14° . For tempering, the blades were kept at 150° C. for twenty minutes. The experimental results are given in Tables VI. and VII., and also in Figs. 12 and 13.

TABLE VI.—*Effect of Quenching Temperature on the Sharpness of 0.9 per Cent. Carbon Steel Blades.*

Quenching Temperature. ° C.	Sharpness.						Durability.
	1st Cut.	3rd Cut.	10th Cut.	20th Cut.	50th Cut.	100th Cut.	
720	106	63	40	31	15	13	5
740	102	80	56	39	28	17	12
770	100	85	57	40	30	18	13
800	66	51	38	34	28	23	24

TABLE VII.—*Effect of Quenching Temperature on the Sharpness of 1·3 per Cent. Carbon Steel Blades.*

Quenching Temperature. ° C.	Sharpness.						Durability.
	1st Cut.	3rd Cut.	10th Cut.	20th Cut.	50th Cut.	100th Cut.	
720	127	84	64	49	32	18	10
740	128	95	67	53	37	21	12
770	122	93	68	51	34	20	13
800	78	60	34	29	22	18	9

In the case of a 0·9 per cent. carbon steel, the initial sharpness slowly decreases at first and then rapidly, as the quenching

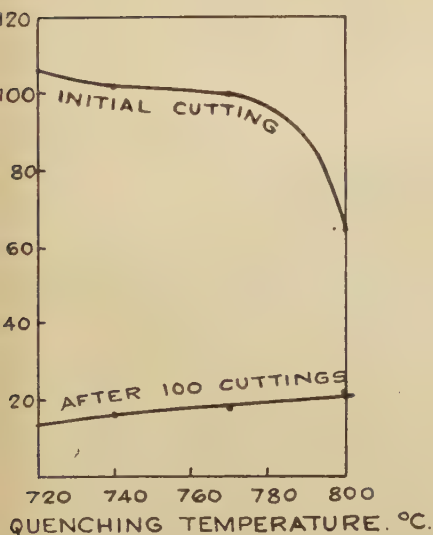


FIG. 12.

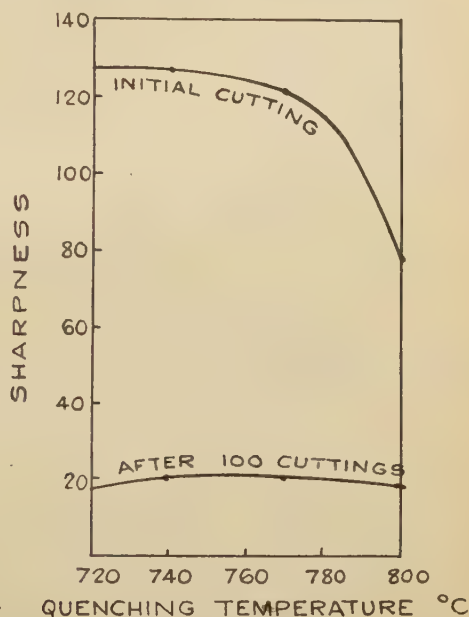


FIG. 13.

temperature increases from 720° to 800° C., but, on the other hand, the durability always increases. In the case of a 1·3 per cent.

carbon steel, the initial sharpness is a maximum at 740° C., as is also the durability. Hence 740° C. is the best quenching temperature.

(c) *Sharpness and Tempering Temperature.*—This test was also made on carbon steel blades containing 0·9 and 1·3 per cent. of carbon, the edge angle being 14°. The quenching temperature was 740° C. The results of experiments are given in Tables VIII. and IX., and also in Figs. 14 and 15.

TABLE VIII.—*Effect of Tempering Temperature on Sharpness of 0·9 per Cent. Carbon Steel Blades.*

Tempering Temperature. °C.	Sharpness.						Durability.
	1st Cut.	3rd Cut.	10th Cut.	20th Cut.	50th Cut.	100th Cut.	
Not tempered	82	63	45	40	34	24	16
100	84	62	46	41	30	23	14
150	102	80	56	39	28	17	12
200	60	48	39	28	22	14	12

TABLE IX.—*Effect of Tempering Temperature on Sharpness of 1·3 per Cent. Carbon Steel Blades.*

Tempering Temperature. °C.	Sharpness.						Durability.
	1st Cut.	3rd Cut.	10th Cut.	20th Cut.	50th Cut.	100th Cut.	
Not tempered	110	80	64	56	37	27	18
100	112	79	66	54	40	27	19
150	127	94	68	55	35	20	12
200	57	52	42	34	25	18	44

The initial sharpness is greatest with a 150° C. tempering temperature, but the greatest value at the 100th cut corresponds to a lower temperature. From the tables it is, however, to be concluded that the best tempering temperature for a blade is 150° C.

(d) *Sharpness and Special Elements added to Carbon Steels.*—Two steels, containing 0·9 and 1·3 per cent. carbon, with special elements, such as chromium, tungsten, and molybdenum, ranging in amount from 0·5 to 1·0 per cent., added to them, were used for making the blades. The quenching and tempering temperatures for special steels are somewhat different from those of carbon

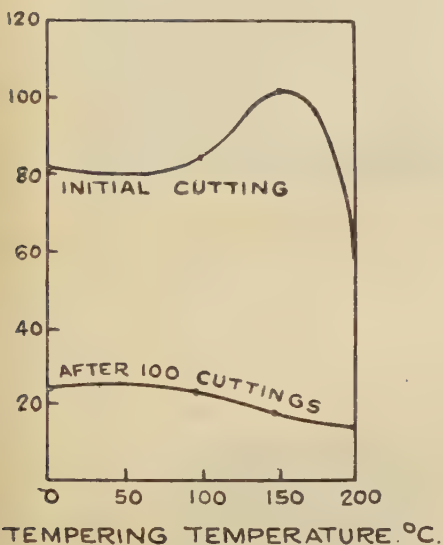


FIG. 14.

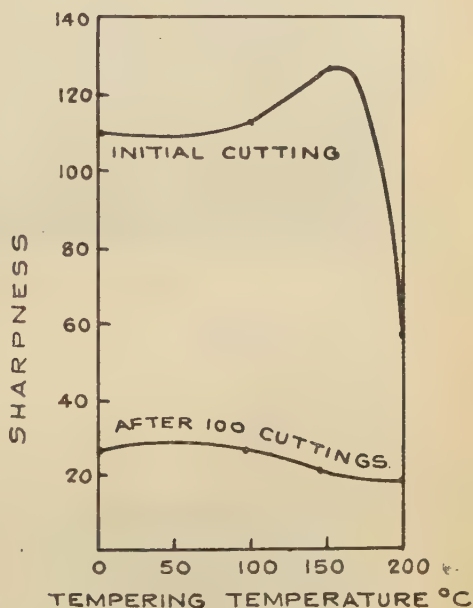


FIG. 15.

steels; by a preliminary experiment, it was found that the best quenching temperature was 800° C. for a 1·3 per cent. carbon blade and 760° C. for a 0·9 per cent. carbon blade, the maximum heating temperature in both cases being 900° C., and that the best tempering temperature was 200° C. Hence the blades were first heated to 900° C., and then, being cooled to the required temperature, were quenched in water. They were tested both in the quenched and tempered states. The results of the test are given in Tables X. to XIII.

TABLE X.—*Special Steels containing 0.9 per Cent. of Carbon. Quenched at 760° C.*

Amount of Special Element Added.	Sharpness.						Durability.
	1st Cut.	3rd Cut.	10th Cut.	20th Cut.	50th Cut.	100th Cut.	
0.5% chromium .	90	72	53	45	52	25	20
1.0% chromium .	90	78	56	46	34	26	21
0.5% tungsten .	85	70	51	43	32	25	29
1.0% tungsten .	83	76	60	47	34	27	20
0.5% molybdenum .	92	74	55	47	35	27	20
1.0% molybdenum .	65	50	43	36	29	24	26

TABLE XI.—*Special Steels containing 0.9 per Cent. Carbon. Quenched at 760° C. and Tempered at 200° C.*

Amount of Special Element Added.	Sharpness.						Durability.
	1st Cut.	3rd Cut.	10th Cut.	20th Cut.	50th Cut.	100th Cut.	
1.0% chromium .	112	70	48	33	25	18	9
1.0% tungsten .	108	72	50	35	26	19	8
0.5% molybdenum .	113	71	40	32	25	18	8
Carbon steel (see Table VI.) .	100	85	57	40	30	18	13

TABLE XII.—*Special Steels containing 1.3 per Cent. Carbon. Quenched at 800° C.*

Amount of Special Element Added.	Sharpness.						Durability.
	1st Cut.	3rd Cut.	10th Cut.	20th Cut.	50th Cut.	100th Cut.	
0.5% chromium .	112	80	66	60	39	29	20
1.0% chromium .	115	88	70	62	40	30	24
0.5% tungsten .	110	81	67	61	38	29	20
1.0% tungsten .	108	86	72	62	41	31	26
0.3% molybdenum .	115	82	70	56	36	28	16
0.5% molybdenum .	114	86	70	60	40	30	24
0.7% molybdenum .	112	88	72	62	41	30	25



FIG. 16.—Section of the cut of a Japanese sword. $\times 3$.



FIG. 17.—Section of the cut of a razor. $\times 3$.

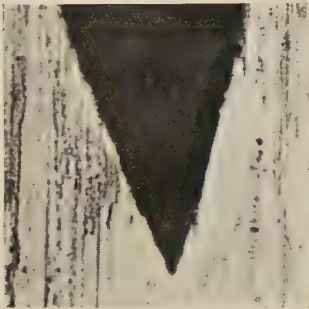


FIG. 18.—Shape of the blade-edge of a Japanese sword before use. $\times 300$.

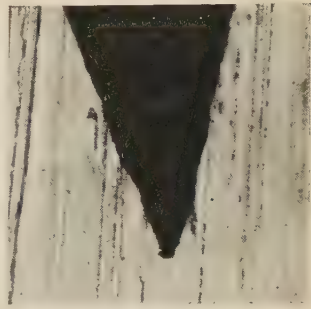


FIG. 19.—Shape of the blade-edge of a Japanese sword after 100 cuts. $\times 300$.

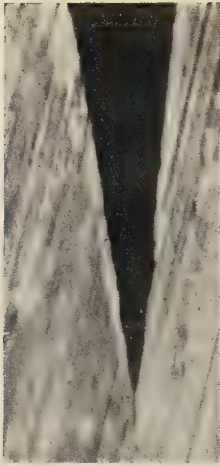


FIG. 20.—Shape of the blade-edge of a razor before use. $\times 300$.



FIG. 21.—Shape of the blade-edge of a razor after 100 cuts. $\times 300$.



FIG. 22.—Blade-edge of a razor as seen from below before use. $\times 300$.



FIG. 23.—Blade-edge of a razor as seen from below after 100 cuts. $\times 300$.



FIG. 24.—Blade-edge before polishing. $\times 300$.

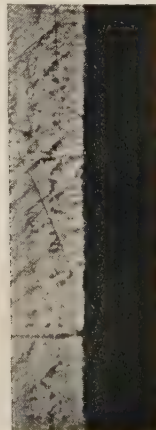


FIG. 25.—Blade-edge after polishing. $\times 300$.

TABLE XIII.—*Special Steels containing 1·3 per Cent. Carbon. Quenched at 800° C. and Tempered at 200° C.*

Amount of Special Element Added.	Sharpness.						Durability.
	1st Cut.	3rd Cut.	10th Cut.	20th Cut.	50th Cut.	100th Cut.	
1·0% chromium .	130	102	75	62	36	22	17
1·0% tungsten .	125	106	78	63	42	24	22
0·5% molybdenum .	131	104	73	61	35	22	18
Carbon steel (see Table IX.) .	127	94	68	55	35	20	12

From the tables it is seen that tempering considerably improves the initial sharpness of these blades, but decreases their durability, and that about 1 per cent. of chromium and tungsten, or 0·5 per cent. of molybdenum, considerably raises the initial sharpness as well as the durability of the carbon steel blades.

SUMMARY.

The present investigation may be summarised as follows :

1. A new machine for testing the sharpness of cutlery and swords has been constructed.

2. The test was applied to different implements and also to old Japanese swords. Among the latter the Masamuné was found to have the highest quality as regards sharpness and "life."

3. The sharpness, N , and the number of repeated cuts, n , are related logarithmically to each other ; that is,

$$N = N_0 e^{-kn}$$

4. In the case of carbon steels containing different amounts of carbon, a 1·3 per cent. carbon blade gave the best results.

5. An addition of 1 per cent. of chromium or tungsten, or of 0·5 per cent. of molybdenum, to carbon steel considerably increases both the sharpness and the life of the blades.

In conclusion, the authors wish to express their best thanks to Mr. Shichisaburo Abé and also to Mr. Sadajiro Kokubo, for their great assistance and useful advice during the course of the present investigation.

CORRESPONDENCE.

Dr. KUREK and Mr. KNAPP (Solingen) presented the following communication in discussion of the paper by Professor Honda and Mr. K. Takahasi on "The Quantitative Measurement of the Cutting Power of Cutlery."

Whereas up to now no regular tests for determining quantitatively the cutting capacity and durability of knives and other cutlery have been made, or at all events published, it is a curious coincidence that experiments on approximately the same lines should have been carried out practically simultaneously by Honda and Takahasi in Japan and at the Technical School for the Steel Goods Industry at Solingen. It was only by chance that the work of Professor Honda was brought to our notice, as it has not previously been published outside Japan. The method of testing cutlery employed by Honda is in principle similar to ours, though, on the one hand, our actual test was somewhat differently performed, with the result that our curves run a different course, and, on the other hand, we aimed more particularly at working out a method which would make possible the control of the quality of the goods regularly produced in a factory, the detection of irregularities and defects, and the making of improvements.

Like Professor Honda, we are of opinion that those methods of testing which depend on pressure *alone* to determine the sharpness of a blade do not give accurate values. For testing cutting power, *both pressure and pull* must be applied, since to use a blade it must be both pressed and pulled, at least where knives are concerned. Honda mentions an apparatus of Professor Iwaoka's which permits the testing of a blade solely by the application of pressure, and he remarks that the values obtained with this apparatus did not accurately represent the cutting capacity which it is required to measure. A similar apparatus (see Fig. A) is also described by Professor Thunberg of Lund in a paper entitled "Acrimetrie."¹ It has been used for testing the sharpness of knife-blades and needle-points. Thunberg uses threads of a known strength and determines first the value O for the load which is necessary under a non-cutting pressure (produced by a thin round bar) to break the loop, and then the value P for the corresponding load under a cutting pressure (applied with the knife-edge). The degree of sharpness is expressed by the formula $A = \frac{O - P}{P}$. This test, as observed, has the disadvantage that cutting is produced only by pressure, and, further, that only a very small part of the edge, equal to the thickness of the thread, is tested, and finally that the *cutting capacity only* is tested and *not the durability* of the edge.

¹ *Zeitschrift für Feinmechanik*, 1922, Nos. 20 and 21.

In the machine used by us (Fig. B) a blade is fixed and the pressure on it is adjustable. It is pressed against thin sheets of paper, and while

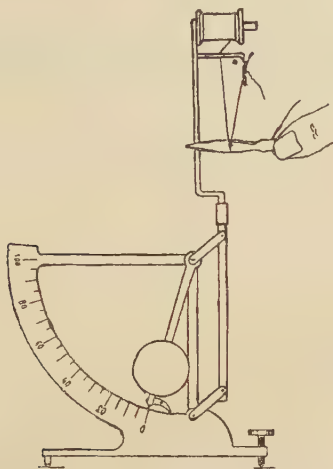


FIG. A.—Professor Thunberg's Apparatus.

under pressure is drawn, not by hand, but mechanically at a definite speed. The distance through which the blade moves can be adjusted

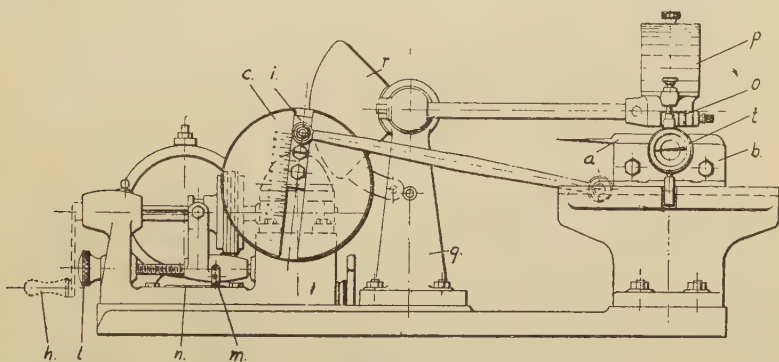


FIG. B.—The Apparatus used by Dr. Kurek and Mr. Knapp.

to different lengths, the speed can be varied, and the number of single cuts or strokes can be read off on a counter. After a considerable number of preliminary trials¹ the machine now in use was constructed

¹ See Report in *Zeitschrift des Vereins für Technik und Industrie*, 1927, Nos. 3 and 4.

with the co-operation of Messrs. Losenhausen in Düsseldorf, and it will shortly be on exhibition at the Berlin Conference on Engineering Materials.

Contrary to Honda, we did not make just *one* cut with a blade and then count the number of sheets of paper cut through, but we determined how many strokes of the slide carrying the blade were necessary to

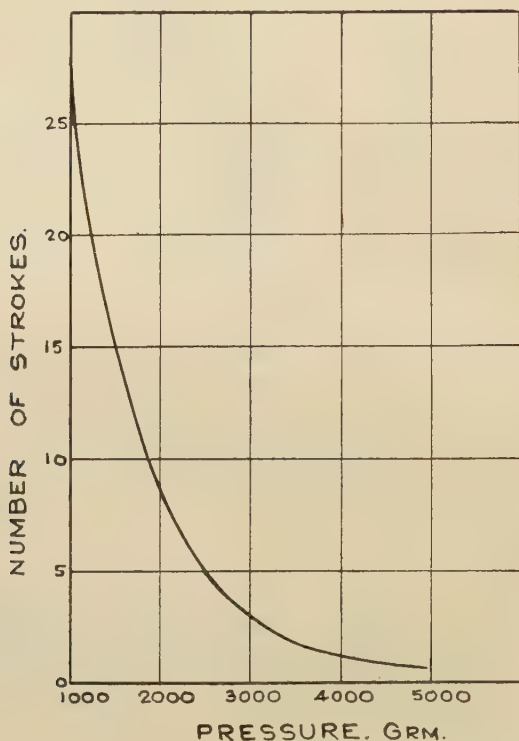


FIG. C.

cut through a definite cross-sectional area of sheets of paper. The section exposed at each cut was about 0.5 sq. cm., the width of the sheets was 9.5 mm., and the section was made up of fifteen thicknesses of paper. The test length of the edge was 70 mm.

The cutting is, of course, dependent principally on the pressure with which the edge is pressed upon the paper sheets. The tests to determine this pressure were made with vegetable knives $3\frac{1}{4}$ in. in length, which were picked out of the stock in the ordinary course of manufacture. The curve in Fig. C indicates the effect on the cutting capacity of varying the pressure. The values from which the curve is plotted each

represent the average of ten tests. The cutting capacity, of course, increases with increasing pressure, just as Honda shows in his Table I. In his case the increase in the cutting capacity is indicated by the increase in the number of paper thicknesses cut at one stroke, whereas in our curves this increase is shown by the fall of the curve, representing the diminution of the number of strokes necessary to cut an equal section of paper.

The decrease in cutting capacity after fifty strokes, the pressure being kept constant, is shown in the curves (Fig. D). In this case pressures of 2000, 2500, and 3000 grm. only were used.

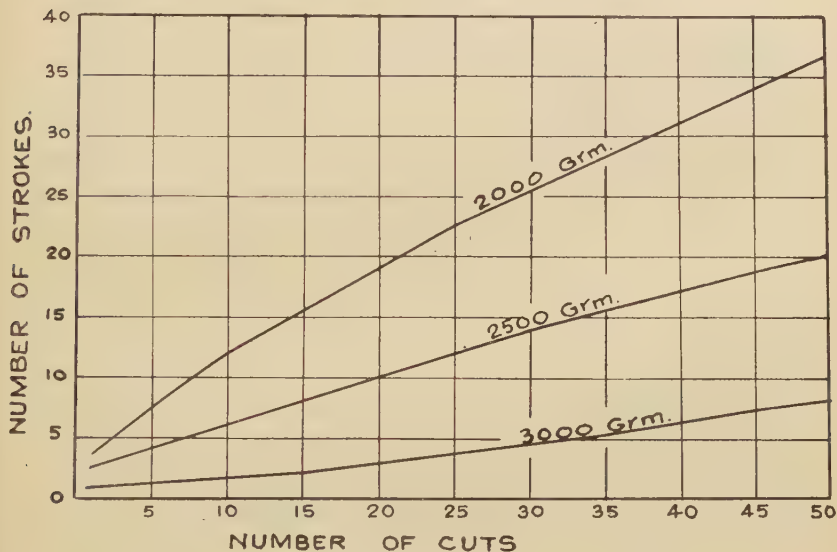


FIG. D.

Likewise the speed with which the blade is reciprocated has an influence, to determine which we made further tests with vegetable knives. In these tests a constant mean pressure was employed and the speed was varied. The values are shown in Fig. E.

We are in complete agreement with Honda that the durability of the edge is a much more important criterion of the quality of knives than the cutting capacity. To determine the durability we again tested vegetable knives, using a mean pressure of 2000 grm. at a speed of thirty revolutions per minute. Two kinds of vegetable knives were tested, taken from the stock currently manufactured by the works, and of each kind ten knives were tested. In the curves shown in Fig. F average values are graphically plotted. It will be noted that the cutting capacity diminishes rapidly at first and then more slowly, and that that of open-hearth steel blades is not so good as that of rustless steel.

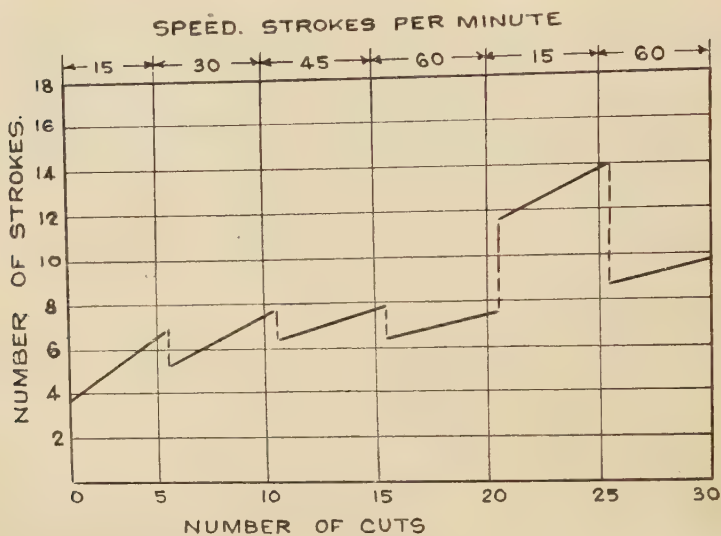


FIG. E.

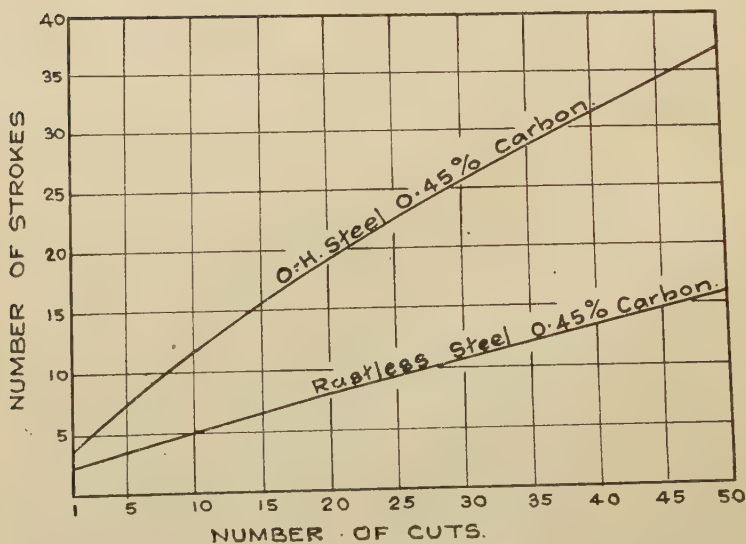


FIG. F.

Unfortunately, we have to admit that values for different knives of the same type vary as widely as 300 per cent. in some cases. The reason for this great difference lies solely in the manner of sharpening the knife, which may result in producing variations in the cutting angle of the blade. It was found that the keener the sharpening, that is, the smaller the cutting angle, the greater was the cutting capacity, just as shown by Honda in Tables II. and III. We accordingly tested the influence—on the cutting capacity and durability—of sharpening by hand and by different kinds of sharpening machines, and we then examined micrographically the form produced by sharpening, but we have not yet

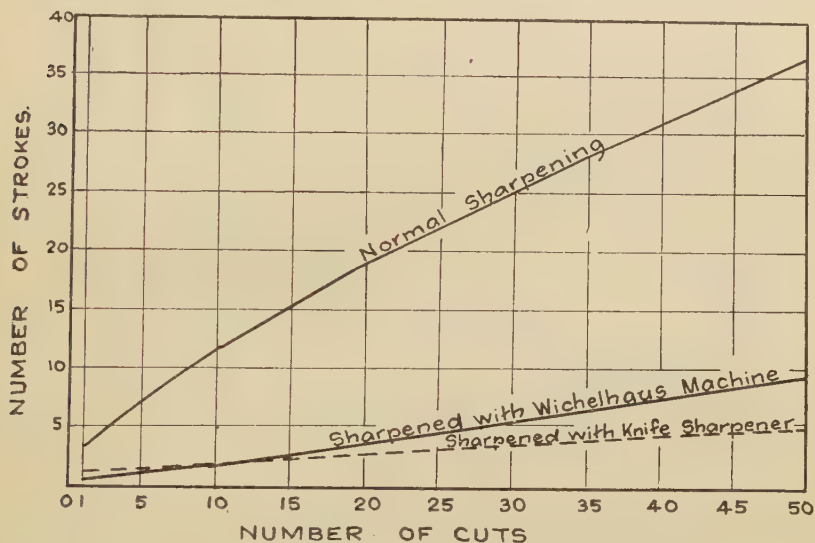


FIG. G.

reached any conclusion as to the most suitable size of the angle for particular kinds of knives and for particular materials (see Fig. G).

Besides the factors already mentioned, the chemical composition of the blade and its heat treatment (hardening and tempering) also affect the cutting capacity and durability of knife-edges. The influence of these factors has been tested by us on so-called standard knives, which were made exactly to one pattern with a straight cutting edge. The knives were heat-treated according to the composition of the material used, the operations being controlled by pyrometers. The values obtained are plotted in curves (Fig. H) and show that a steel with 1.3 per cent. carbon gives both the best cutting capacity and durability of edge.

To permit of a comparison of the different values it is absolutely necessary to devise a scale for measuring the durability or sharpness.

In the experiments made we used the following formula to express the cutting capacity after 25, 50, and 100 cuts :— $SH_{100} = 17.5 (2:35)$. This means that, while in the first test two cuts were necessary to cut paper sheets of a sectional area of 0.5 sq. cm., for cutting the same section at the hundredth test thirty-five cuts were necessary. It is desirable, in order to have comparative values always at hand, to fix a definite sectional area of the material to be cut, the maximum number

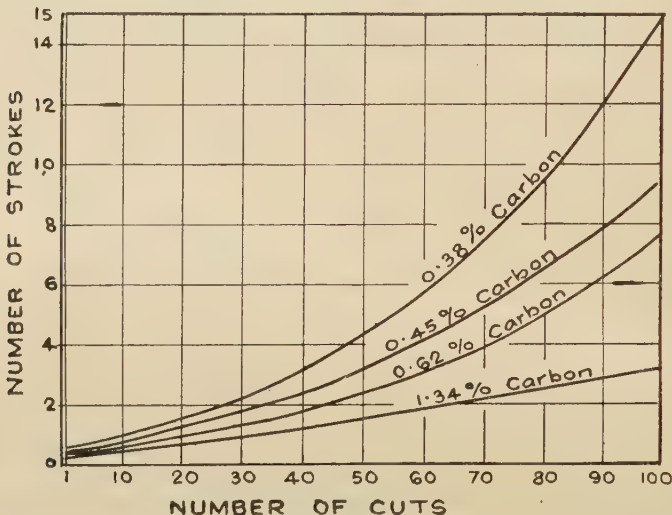


FIG. H.

of separate tests, the amount of pressure, the speed of stroke, and the length of cutting edge, thus :

Sectional area of paper cut	.	.	.	1 sq. cm.
Pressure	.	.	.	1 kg.
Cuts per minute	.	.	.	10
Length of edge to be tested	.	.	.	100 mm.
Number of tests	.	.	.	100

The values in Honda's Tables V. to XIII., obtained with knives of his own manufacture, are comparable with one another, but not with those obtained with our machine. The great difference between his and our results lies particularly therein that he counts the sheets of paper cut through at one stroke and then those which are sheared after the hundredth cut, while we count the number of strokes necessary to cut a definite sectional area of paper in the first test and in the hundredth test. In our test the edge becomes much more blunted on account of having to cut through a much larger quantity of paper.

The report of the tests carried out by us is to form the basis of a doctor's thesis by Mr. Knapp, which is shortly to be submitted to the

Technical High School at Aachen. We considered it desirable, however, in connection with the compendious work of Honda and Takahasi, to make a short report on our experiments, and we intend at an early date to publish an abstract of the work in *Stahl und Eisen*.

Mr. P. B. PARKS (Sheffield) wrote: In the first place, I should like to thank the authors for an extremely interesting and instructive paper on a matter which seems hitherto to have been carefully avoided. This paper, so far as I can find out, is the first one to be submitted to the Institute which concerns solely the cutting power of cutlery, about which there is still a great deal to be discovered.

The reason for the undoubtedly superior cutting qualities of the genuine shear steel blade compared with the best cast or stainless steel blades has never yet been satisfactorily explained. There is no doubt that whilst the carbon content of the steel and the geometry of the edge of the blade are very important factors, nevertheless in shear steel the presence of oxides and silicates, unavoidably—one might say, deliberately—introduced as a result of its method of manufacture, plays a very important part in producing that saw-like edge which is characteristic of the shear steel blade.

On p. 367 the authors mention a number of articles of which they measured the sharpness, and I note that fifth on the list comes "a Japanese stainless kitchen knife," whilst the sixth is "an ordinary kitchen knife." This latter description is somewhat vague, and it would be very interesting to know whether this particular blade was made of shear, crucible, or possibly cheap Bessemer or Siemens steel. I think that much valuable data could be collected by making a series of tests on the author's machine on similar knives made of various steels. These knives could be heat-treated according to the type of steel and then ground with equal edge-angles, which could be accomplished without much trouble by machine grinding.

The most remarkable feature about the paper, to me, is that the question of hardness is entirely ignored. I do not think the word "hardness" appears once throughout its entire length, and certainly there are no Brinell or scleroscope readings given, or mention of any ever having been taken. On this account I think that a great deal of the data given is rendered useless, or at any rate is not nearly so valuable as it might have been had hardness figures been determined at the same time, since there must be a definite ratio between hardness and durability. An equally good edge, perfect geometrically, can be put on an ordinary piece of iron or mild steel, but its very brief life is due primarily to its inability to stand up to any abrasive action, such as cutting, on account of its softness. The ability of a steel to harden may (or may not, as in the case of the stainless steels) be in proportion to the amount of carbon present, but before measuring its cutting powers it is surely essential to see that the article is in a properly hardened state. It was purely on this account that stainless steel, so far as cutlery was concerned, got

such an evil reputation in its early days. It was said very generally, and rightly, that it would not keep its edge, simply because, as was eventually proved, the knives were not hard enough. Stainless steel was not then understood by the cutlery forgers, and they were giving it the same heat treatment as they had given to shear and other straight carbon steels. Therefore, it seems to me imperative that before any tests can be made on the cutting power and, particularly, the durability of a blade, one must make sure, quite apart from its analytical composition, that it has a sufficiently high hardness value, and that in comparing different knives they should have equal hardness values, or that, conversely, the variations in hardness, if any, should be taken into account. For instance, I have found, as a result of a large number of tests, that to give a stainless steel knife a fair chance of keeping its edge during constant use, its hardness should be between 500 and 550 Brinell. It is true, of course, that this hardness can be obtained by different methods of heat treatment, and that blades of equal hardness heat-treated in different ways exhibit varying degrees of toughness or pliability; but so far as the durability of the edge is concerned, I think that a knife of over 500 Brinell will outlast one of under that figure.

Again, on p. 365, the authors, in describing the method of polishing up their implements before testing, state that, "The edge was then examined under a microscope, and if it was not satisfactory the blade was re-polished until its edge became approximately straight." I have found that it is very unreliable to suppose that a straight edge is the sharpest for all blades. Microscopic examination of the edges of proved good and bad safety razors and long razors has shown that whereas a good example of the former generally has a straight-line edge, a good specimen of the latter almost invariably has a serrated edge under the same magnification.

At the top of p. 370 the authors conclude their investigations on the effect of the carbon content on the sharpness with the sweeping statement "that a content of 1.30 per cent. carbon is the best for a blade." This is most probably correct for certain kinds of blades, such as razors, and perhaps so for all blades when considering initial sharpness only, but my personal experience is that blades which have to withstand any kind of shock, such as pruning knives, butchers' knives, fish choppers, or even carving knives, if made of a hypereutectoid steel, will not have a very long life. As an instance of this, several years ago I had to investigate a number of butchers' knives which were returned to our works fractured or "snipped" on the edges. There was no sign of the material having been overheated, nor was the hardness excessive. On the other hand, the carbon content was over 1.20 per cent., and the fractures followed the cementite crystal boundaries in practically every case. Records eventually proved that this particular batch of knives had been made from some shear steel produced during the latter part of the Great War, when the converting of Swedish iron bars was unreliable, owing to the lack of suitable charcoal.

THE EFFECT OF MASS IN THE HEAT TREATMENT OF NICKEL STEEL.¹

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(WORK CARRIED OUT FOR THE ENGINEERING RESEARCH BOARD OF THE
DEPARTMENT OF SCIENTIFIC AND INDUSTRIAL RESEARCH.)

THE failure in service of a number of pinions, of relatively large size, from the double reduction gears of marine steam-turbines has drawn attention to the influence of mass on heat treatment. The present investigation was undertaken to ascertain the manner in which the mechanical properties and microstructure of the material used for these pinions vary with the size of the heat-treated piece.

It is well known that in the heat treatment of steel the size of the piece has an effect on the properties obtained. Some tests have been carried out by E. F. Law² on a steel containing 0.34 per cent. of carbon, 0.73 per cent. of manganese, 0.20 per cent. of nickel, and the usual impurities. This steel was heated in 18-inch cubes, and tensile tests made at regular intervals across the section.

The results showed :

- (1) With air cooling the results of all these tests were practically identical.
- (2) The effect of oil-quenching was as apparent in the centre of the cube as at the outside.
- (3) Water-quenching showed a very decided variation from the surface to the centre of the cube.

Tests on the effect of heat treatment on bars varying from $\frac{1}{16}$ inch to 3 inches in diameter have been carried out in connection

¹ This paper was read and discussed at the Annual Meeting in June 1926, but its publication was deferred pending further experiments by the authors, which have now been completed.

² *Journal of the Iron and Steel Institute*, 1918, No. I. p. 333.
1927—ii.

with the research of the Steel Research Committee¹ of the Institution of Automobile Engineers and the Society of Motor Manufacturers and Traders in 1920. The tests show that there is a reduction of the ultimate tensile stress with the larger sizes of bar. The approximate amounts of this reduction are given in Table I.:

TABLE I.

Class of Steel.	Reduction of Tensile Strength. Per Cent.	Range of Bars. Diameter. Inches.
0.20 per cent. carbon case-hardening steel	25	} $\frac{11}{16}$ to $2\frac{1}{8}$
6 per cent. nickel case-hardening steel	31	
0.45 per cent. carbon steel	12-15	} $\frac{11}{16}$ to 3
1.7 per cent. nickel-chrome steel	12	
3.3 per cent. nickel-chrome steel	5	

The use of alloy steels has made it possible to obtain, in relatively large pieces, properties which would not be attainable in a simple carbon steel; this is due to the fact that certain alloying elements retard the transformations of steel, and thus make it possible to harden an alloy steel in which they are present, by cooling at rates considerably less than those necessary in straight carbon steels. It is, however, clear that, even with alloy steels, the rates of cooling possible with ordinary methods of quenching will not be effective in hardening very large objects throughout their mass.

The tests of the Steel Research Committee on mass effect did not include a $3\frac{1}{2}$ per cent. nickel steel, and the largest size of bar tested was 3 inches in diameter. Further, the test-pieces were taken from the centres of the bars and therefore did not give any indication of the variation, if any, in the mechanical properties of the outer and inner section of the bars. Further investigation, on the lines followed in the present research, was therefore desirable.

¹ "Some Notes of the Report of the Steel Research Committee," by J. H. S. Dickenson, *Proceedings of the Institution of Automobile Engineers*, 1920-21, vol. xv. p. 99.

MATERIALS USED IN THE INVESTIGATION.

Particulars of the materials are given below :

Lab. Mark.	Particulars of Sample.
ACM	Nickel steel pinion forging. This forging was large enough to obtain pieces up to 10 inches in diameter
AEF	Four bars of nickel steel 4 inches in diameter and 60 inches long
AEG	" " 2 " " " 60 " "

The steels were heat-treated in the form of round bars of four different sizes—viz. 2, 4, 7, and 10 inches in diameter, and in lengths of about 20 inches. The chemical analyses of the materials are as follows :

	AEG. 2-Inch Bar.	AEF. 4-Inch Bar.	ACM. 7- and 10-Inch Bars.
	Per Cent.	Per Cent.	Per Cent.
Carbon . . .	0.364	0.370	0.306
Silicon . . .	0.186	0.196	0.191
Sulphur . . .	0.025	0.025	0.034
Phosphorus . . .	0.030	0.031	0.037
Manganese . . .	0.425	0.410	0.720
Nickel . . .	3.43	3.42	3.57
Chromium . . .	0.208	0.199	trace

HEAT TREATMENT.

The heating of the material was carried out in a recuperative furnace designed to give uniform heating at high temperatures. This had to be considerably modified before sufficiently uniform heating at the moderate temperatures required for the present work could be obtained. After a number of trials, however, good uniformity was secured.

TEMPERATURE MEASUREMENT.

The uniformity of the temperature of the furnace was checked with two platinum—platinum-rhodium thermocouples inserted in a "dummy." This dummy was a steel bar 22 inches long and

4 inches in diameter, placed along the back of the furnace, so that one end was near the gas entrance, the other near the exit. The thermocouples, protected by silica tubes, were placed in holes drilled in the centre of each end of the dummy, with their junctions 2 to 3 inches inside the dummy. The actual treatment temperature was measured by means of a third thermocouple, inserted in a hole drilled radially in one of the experimental bars near one end, in such a manner that the junction was within 1 inch of the centre of the bar. All the couples were calibrated against a standard before, and at intervals during, the investigation. No appreciable changes were observed during the course of the experiments.

PROCEDURE.

In order to facilitate the rapid removal of the larger pieces from the furnace to the quenching tank, some special apparatus was constructed. The furnace was provided with a counter-balanced iron-bound brick door, so that it could be rapidly opened for the removal of the bars. Bars whose diameter exceeded 4 inches were rolled into and out of the furnace on steel rails, which could be rapidly removed and placed in position when the furnace door was open. Bars up to 4 inches in diameter were fed into and removed from the furnace by hand. For larger pieces a crane was needed. The quenching bath contained 250 gallons of cotton-seed oil, which was stirred by air blown through it to promote rapid and even quenching. In order to avoid the inconvenience due to smoke arising from the ignition of the oil, a layer of vapour of carbon tetrachloride was maintained in the top of the tank immediately over the oil; this excluded the air and prevented the oil from taking fire during the quenching operation.

In carrying out an experiment the dummy bar was placed in the furnace, which was heated up to the required temperature, and the conditions were so adjusted as to give uniformity of temperature from one end of the bar to the other. The specimen was then placed in the furnace, close to the dummy bar, and a thermocouple was inserted into the hole at one end. The temperature of the bar was allowed to rise until the interior reached the desired quenching temperature, which was maintained for

about twenty minutes before quenching. By carefully watching the temperatures of both the dummy bar and the bar undergoing heat treatment, and adjusting the gas supply so that no considerable differences in temperature occurred between them, it was possible to avoid appreciable variations in temperature within the specimen used. The steel was removed from the furnace and placed in the oil-bath, with the aid of a crane if necessary, but the time taken was always sufficiently short to prevent any serious drop in temperature between the time of opening the furnace door and the quenching operation.

The following is a typical time record of an experiment :

Dimensions of piece	7 in. × 20 in.
Piece placed in furnace	12.45 P.M.
Piece taken out	4.55 P.M.
Temperature	840° C.
Difference in temperature of ends of dummy	20° C.
Time from opening of furnace door to quenching of piece	45 seconds

The piece was then left overnight in the quenching bath. In the case of 7-inch and 10-inch bars, only one was heat-treated at a time. Two 4-inch bars were heated side by side, the thermocouple being inserted in the one nearest the door. Eight 2-inch bars were heated together piled in pyramid form on the hearth of the furnace with the thermocouple thrust in among them.

In tempering, the specimens were reheated at the required temperature for half an hour and quenched in water. In the case of the larger sizes it was desired to avoid tempering in the mass, on account of the expense of preparing test-pieces from the large number of samples that would be required; such machining would have added greatly to the cost of the investigation. A series of preliminary tests on bars 4 inches in diameter, described later in the Report, showed that the size of the piece was relatively unimportant in tempering, and tempering has therefore been done on small test-pieces cut from the hardened bars.

MECHANICAL TESTS.

Samples 7 inches and 10 inches in diameter, turned from the pinion forging, and samples from the 2-inch and 4-inch diameter bars, were heat-treated in the following way :

- | | | | | |
|-----|---|---------|-----|---------|
| (1) | Normalised at 840° C. | | | |
| (2) | Oil-hardened at 840° C. | | | |
| (3) | Oil-hardened at 840° C. and tempered at | 300° C. | | |
| (4) | " " | " " | " " | 400° C. |
| (5) | " " | " " | " " | 500° C. |
| (6) | " " | " " | " " | 600° C. |
| (7) | " " | " " | " " | 650° C. |
| (8) | " " | " " | " " | 700° C. |

Mechanical tests were carried out on pieces cut from near the centre and near the outside of the bars.

The mechanical tests were :

A. *Tensile Tests*, giving :

Limit of proportionality.

Yield stress.

Ultimate stress.

Modulus of elasticity.

Percentage reduction of area at fracture.

Percentage extension on a gauge length equal to four times the square root of the original cross-sectional area.

In order to obtain test-pieces as near to the centre and outside of the bars as possible a small type of test-piece was adopted for these tests, having a diameter of 0.358 inch, cross-sectional area of 0.1007 square inch, and gauge length of $1\frac{1}{4}$ inches.

The extensions of the test-piece, within the yield stress, were measured by a mirror extensometer, and the limits of proportionality and modulus of elasticity were calculated from the curves given by the plotted results. The yield stresses (where a yield was noted) were taken by means of the drop of the beam as fixed by the British Engineering Standards Association.¹

B. *Notched-Bar Tests*.—These were carried out on the British Engineering Standards Association cantilever type test-piece with three notches.² A 120 foot-pound Izod machine was used for carrying out the tests, the conditions of which were as follows :

Temperature	:	:	:	:	:	15° to 25° C.
Energy of blow	:	:	:	:	:	120 foot-pounds
Cross-section of test-piece (exterior)	:	:	:	:	:	10 × 10 millimetres
"	"	"	"	"	"	(at bottom of notch) 10 × 8 "
Form of notch	.	.	.	.	.	45° Vee-notch, 2 millimetres deep, 0.25 millimetre root radius

¹ See *B.E.S.A. Report*, No. 58, 1911.

² *Ibid.*, No. 131, 1920.

C. Brinell Hardness Tests.—These were made on the broken Izod test-pieces, using a ball 5 millimetres in diameter and a load of 750 kilogrammes.

In some cases additional hardness determinations were made on sections cut from the bars. In these cases a ball 10 millimetres in diameter and a load of 3000 kilogrammes were employed, which, it should be noted, give the same hardness as a ball 5 millimetres in diameter with a load of 750 kilogrammes, so that the results obtained under the two conditions are strictly comparable.

PRELIMINARY INVESTIGATION ON 4-INCH DIAMETER BARS.

Before arranging for the full series of tests a preliminary investigation was carried out on 4-inch diameter bars. Pieces were cut from these bars and subjected to the heat treatment and mechanical tests shown in Table II.

TABLE II.

Heat Treatment.	Mechanical Tests.
Normalised in mass at 840° C.	Brinell hardness tests showing distribution of hardness across the section. Tensile and notched-bar tests from near centre and near outside of bar.
Oil-quenched in mass from 840° C.	Brinell hardness, tensile, and notched-bar tests from near centre and near outside of bar.
Test-pieces prepared from oil-quenched bar and tempered at : (a) 500° C. (b) 700° C.	Tensile and notched-bar tests from near centre and near outside of bar.
Oil-quenched in mass from 840° C., and tempered in mass at 500° C.	Brinell hardness tests after quenching and also after tempering. Tensile and notched-bar tests (after tempering) from near centre and near outside of bar.
Oil-quenched in mass from 840° C., and tempered in mass at 700° C.	Do. Do.

The Brinell hardness tests on sections cut from the bars gave in some instances an exceptionally high value at the centre of the bar. Microscopic examination showed a small segregation at this point. The test-pieces taken near the centre of the bar were accordingly cut so as to avoid this segregation. The results obtained are summarised in Tables III., IV., and V.

TABLE III.—*Tensile Tests on 4-Inch Diameter Bars.*
(*Preliminary Investigation.*)

Heat Treatment.	Outside of Bar.						Centre of Bar.					
	Limit of Proportionality. Tons per Square Inch.	Yield Stress. Tons per Square Inch.	Ultimate Stress. Tons per Square Inch.	Modulus of Elasticity $\times 10^{-6}$. Lbs. per Square Inch.	Extension. Per Cent.	Reduction of Area. Per Cent.	Limit of Proportionality. Tons per Square Inch.	Yield Stress. Tons per Square Inch.	Ultimate Stress. Tons per Square Inch.	Modulus of Elasticity $\times 10^{-6}$. Lbs. per Square Inch.	Extension. Per Cent.	Reduction of Area. Per Cent.
Normalised in mass at 840° C.	27.5	29.5	44.6	28.9	27	51	23.8	27.5	45.0	28.2	26	43
Oil-hardened in mass at 840° C.	10.7	42.3 ¹	53.3	29.5	20 ²	41	10.7	47.0 ¹	57.7	29.4	16 ²	32
Oil-hardened in mass at 840° C. Tempered in mass at 500° C.	36.2	40.3 ¹	53.7	29.1	26	56	32.2	38.8 ¹	54.4	28.9	24	49
Oil-hardened in mass at 840° C. Tempered in mass at 700° C.	27.0	36.2	48.5	28.9	30	64	24.8	31.8	47.5	29.3	31	62
Oil-hardened in mass at 840° C. Tempered as test-piece at 500° C.	28.2	39.4	51.4	29.0	23	56	28.3	38.6	52.0	29.0	24.5	54
Oil-hardened in mass at 840° C. Tempered as test-piece at 700° C.	17.0	33.9	50.0	29.0	24 ²	57	15.6	33.2	50.5	29.0	24.5 ²	53

¹ Yield indefinite.² Fractured less than $\frac{1}{4}$ inch from gauge mark.

TABLE IV.—Notched-Bar Tests on 4-Inch Diameter Bars.
(Preliminary Investigation.)

Test Mark.	Heat Treatment.	Energy absorbed in Foot-Pounds.							
		Outside of Bar.				Near Centre of Bar.			
		First Notch.	Second Notch.	Third Notch.	Average.	First Notch.	Second Notch.	Third Notch.	Average.
AEF3A6 and 7	Normalised in mass at 840° C.	25·6	29·2	26·6	27·1	24·0	25·8	27·2	25·7
AEF2A3 and 5	Oil-hardened in mass at 840° C.	17·3	17·0	16·6	17·0	13·3	11·3	11·4	12·0
AEF1C6 and 7	Oil-hardened in mass at 840° C. Tempered in mass at 500° C.	32·4	34·3	35·7	34·1	26·9	27·8	25·0	26·6
AEF1D6 and 7	Oil-hardened in mass at 840° C. Tempered in mass at 700° C.	51·9	57·3	64·3	57·8	55·1	47·5	50·0	50·9
AEF2A7 and 9	Oil-hardened in mass at 840° C. Tempered as test-pieces at 500° C.	40·9	35·5	41·3	39·2	25·2	27·1	29·8	27·4
AEF2A11 and 13	Oil-hardened in mass at 840° C. Tempered as test-pieces at 700° C.	52·1	55·1	46·8	51·3	35·3	42·7	44·6	40·9

TABLE V.—*Brinell Hardness Tests on 4-Inch Bars.**(Preliminary Investigation.)*

Test Mark.	Heat Treatment.	Brinell Hardness Number.			
		At Centre. (A)	$\frac{3}{4}$ Inch from Centre. (B) ¹	$1\frac{1}{2}$ Inches from Centre. (C) ¹	Average Value, neglecting Values marked ² .
AEF3A8	Normalised in mass at 840° C. (Bar 4 inches diameter, 12 inches long)	203	199	194	199
AEF2A1	Oil-quenched in mass at 840° C. (before cutting out test-pieces for tempering) (4 inches diameter, 20 inches long)	248	248	245	247
AEF1B2	Oil-quenched in mass at 840° C. (4 inches diameter, 20 inches long)	257 ²	240	241	241
AEF3B1	Oil-quenched in mass at 840° C. (4 inches diameter, 14 inches long)	265	266	254	262
AEF3C1	Oil-quenched in mass at 840° C. (4 inches diameter, 14 inches long)	261	257	259	259
AEF1C2	Oil-quenched in mass at 840° C., and tempered in mass at 500° C.	317 ²	262	247	255
AEF1C8	After quenching, before tempering After tempering	295 ²	243	243	243
AEF1D2	Oil-quenched in mass at 840° C., and tempered in mass at 700° C.	350 ²	274	269	272
AEF1D8	After quenching, before tempering After tempering (Bar 4 inches diameter, 14 inches long)	233 ²	215	219	217

¹ Average of four distinct determinations, all of which were in good agreement.² Note these high values, all of which were obtained at the centre of bar AEF1.

NOTES ON TESTS (PRELIMINARY INVESTIGATION ON THE 4-INCH DIAMETER BARS).

Tensile Tests (Table III).—The limit of proportionality of the pieces which were tempered in the form of the roughly turned specimen is lower than that obtained on pieces cut from the bar tempered in mass at the same temperatures. The effect of this variation in the method of tempering on the other tensile results is not appreciable.

Notched-Bar Tests (Table IV).—These show, in every case, that the average value obtained from test-pieces near the outside of the bar is slightly higher than that from test-pieces taken near the centre of the bar.

Brinell Hardness Tests (Table V).—Results are given on six pieces oil-hardened at 840° C. These show some variations with different pieces hardened from the same temperature at different times.

The results as a whole show that the Brinell hardness numbers follow the ultimate stress in the tensile test.

COMPLETE INVESTIGATION.

The programme of tests was carried out as described on p. 390, and the results have been tabulated as follows :

Results on 2-Inch Diameter Bars.—Pieces of the 2-inch diameter bars (AEG, Table I.), 14 inches long, were heat-treated in mass in the following ways :

Normalised in mass at 850° C.					
Oil-hardened in mass at 850° C.					
Oil-hardened in mass at 850° C. and tempered in mass at 300° C.					
"	"	"	"	"	400° C.
"	"	"	"	"	500° C.
"	"	"	"	"	600° C.
"	"	"	"	"	650° C.
"	"	"	"	"	700° C.

Test-pieces were cut from the centre and near the outside of the bars, and the results of tensile, notched-bar, and Brinell tests are given in Tables VI., VII., and VIII. Sections were cut from each of the bars after oil-hardening and before tempering, and the Brinell results from these are given in Table IX. They

TABLE VI.—*Tensile Tests on 2-Inch Diameter Bars. (Test Mark, AEG.)*

Heat Treatment.	Outside of Bar.						Centre of Bar.					
	Limit of Proportionality. Tons per Square Inch.	Yield Stress. Tons per Square Inch.	Ultimate Stress. Tons per Square Inch.	Modulus of Elasticity $\times 10^{-4}$. Lbs. per Square Inch.	Extension. Per Cent.	Reduction of Area. Per Cent.	Limit of Proportionality. Tons per Square Inch.	Yield Stress. Tons per Square Inch.	Ultimate Stress. Tons per Square Inch.	Modulus of Elasticity $\times 10^{-4}$. Lbs. per Square Inch.	Extension. Per Cent.	Reduction of Area. Per Cent.
Normalised in mass at 850° C. .	23.8	29.8	46.2	29.0	28	51	20.8	...	46.0	29.4	26	44
Oil-hardened in mass at 850° C. .	15.6	...	60.6	28.7	14	50	11.9	...	60.6	27.5	10	23 ¹
Oil-hardened in mass and tempered in mass at 300° C. .	32.1	...	85.0	28.7	8	30 ¹	23.8	...	78.7	29.0	9	19
Do. at 400° C. .	39.7	...	77.8	28.7	11	39	27.4	...	70.2	29.2	6	16
Do. at 500° C. .	44.5	57.1 ²	61.4	29.0	19	56	34.7	49.1 ²	56.0	29.0	19	55
Do. at 600° C. .	38.2	48.2 ²	52.6	29.2	24	61	29.8	44.7 ²	50.7	29.2	25	61
Do. at 650° C. .	32.6	...	50.1	29.1	25	65	23.8	...	47.8	29.0	28	65
Do. at 700° C. .	12.5	...	57.4	29.6	...	41 ³	16.1	...	59.5	29.0	10	29 ³

¹ Fracture near gauge point.² Yield small.³ Fracture outside gauge mark.

TABLE VII.—*Average Notched-Bar Results from 2-Inch Diameter Bars.*
(Test Mark, AEG.)

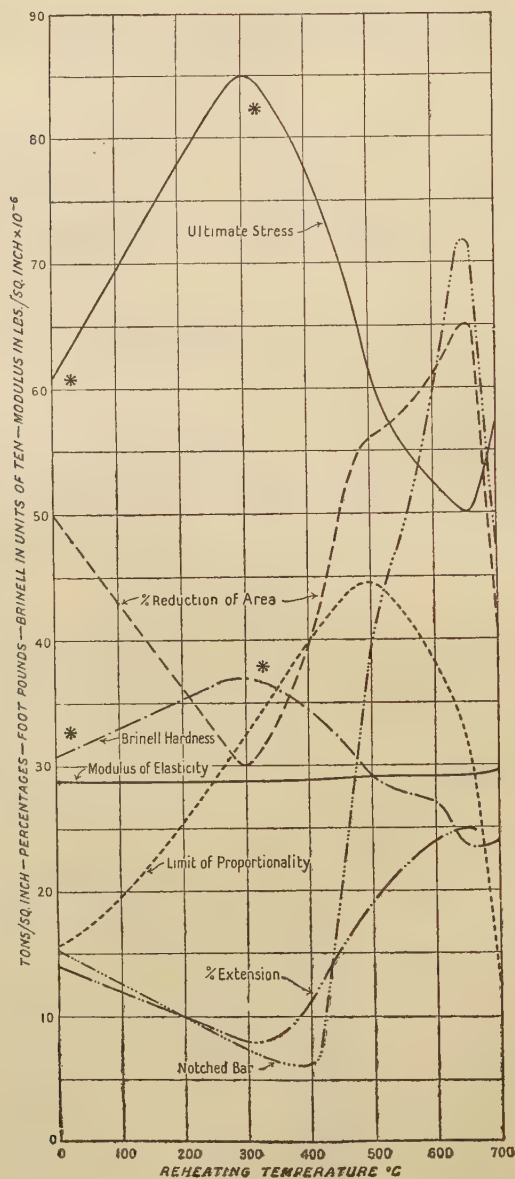
Heat Treatment.	Energy absorbed in Foot-Pounds.							
	Outside of Bar.				Centre of Bar.			
	First Notch.	Second Notch.	Third Notch.	Average.	First Notch.	Second Notch.	Third Notch.	Average.
Normalised in mass at 850° C. . . .	24.9	25.6	23.8	24.8	26.2	24.6	24.4	25.1
Oil-hardened in mass at 850° C. . . .	19.0	15.9	10.9	15.3	13.2	9.0	8.9	10.4
Oil-hardened in mass and tempered in mass at 300° C. . .	7.8	6.3	7.4	7.2	6.3	4.9	5.5	5.6
Do. at 400° C. . . .	7.1	5.3	6.2	6.2	7.6	6.7	5.3	6.5
Do. at 500° C. . . .	40.6	37.9	41.5	40.0	40.7	43.0	45.8	43.2
Do. at 600° C. . . .	57.4	61.1	58.3	58.9	62.3	64.1	62.2	62.9
Do. at 650° C. . . .	70.4	72.5	72.2	71.7	68.8	72.8	72.8	71.5
Do. at 700° C. . . .	31.3	47.5	63.3	47.3	55.8	61.7	66.9	61.5

TABLE VIII.—*Brinell Hardness Numbers on 2-Inch Diameter Bars*
(from Notched-Bar Pieces). (Test Mark, AEG.)

Heat Treatment.	Outside of Bar.			Centre of Bar.		
	(A)	(B)	Mean.	(A)	(B)	Mean.
Normalised in mass at 850° C. . . .	209	203	206	197	199	198
Oil-hardened in mass at 850° C. . . .	{ 295 290 }	{ 363 279 }	307	{ 269 289 }	{ 309 277 }	286
Oil-hardened in mass and tempered in mass at 300° C. . . .	{ 372 360 }	{ 359 387 }	369	{ 350 360 }	{ 350 360 }	355
Do. at 400° C. . . .	{ 337 333 }	{ 363 375 }	352	{ 313 304 }	{ 317 315 }	312
Do. at 500° C. . . .	{ 302 295 }	{ 285 281 }	291	247	245	246
Do. at 600° C. . . .	276	267	271	227	211	219
Do. at 650° C. . . .	240	230	235	218	205	211
Do. at 700° C. . . .	{ 273 253 }	{ 211 223 }	240	{ 220 207 }	{ 207 205 }	210

(A) One end of test-piece.

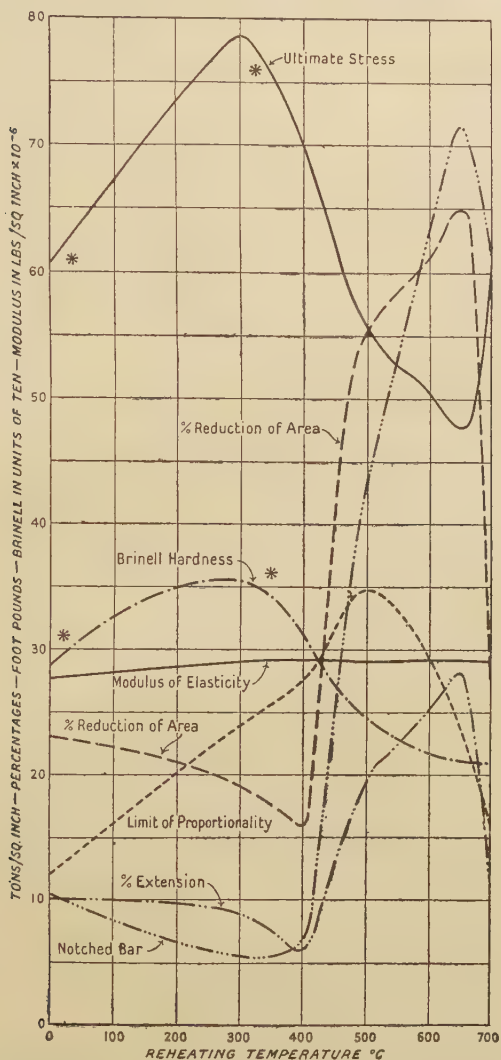
(B) Other end of test-piece.



* Values variable; see authors' reply to discussion, pp. 433-453.

FIG. 1.—Outside of 2-Inch Diameter Nickel Steel Bar.

show a fairly considerable variation of hardness (282 to 364) in the



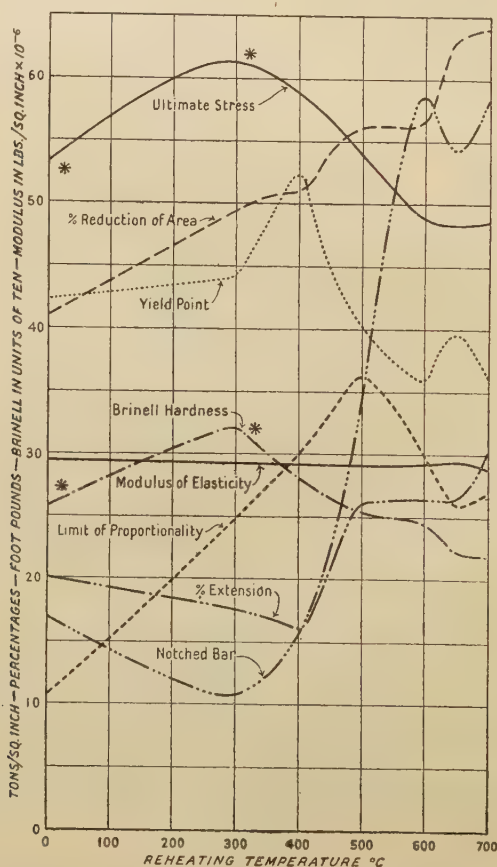
* Values variable; see authors' reply to discussion, pp. 433-453.

FIG. 2.—Centre of 2-Inch Diameter Nickel Steel Bar.

various bars oil-hardened from the same temperature. (See graphs, Figs. 1 and 2.)

TABLE IX.—2-Inch Diameter Bars. Brinell Hardness Numbers of Sections Cut 2 Inches from End of Bar before Tempering.

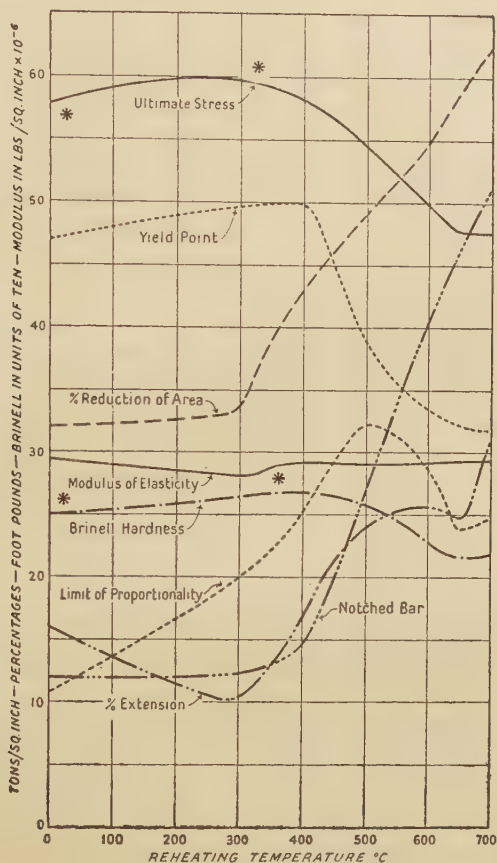
Heat Treatment.	Marks on Bar.	Hardness Number.	
		At Centre.	$\frac{1}{2}$ Inch away from Centre.
Normalised at 850° C.	AEG2A1	205	208
Oil-hardened in mass at 850° C.	AEG2B1	301	301
Do. Bar afterwards tempered in mass at 300° C.	AEG2C1	364	360
Do. at 400° C.	AEG2D1	340	372
Do. at 500° C.	AEG3A1	319	342
Do. at 600° C.	AEG3B1	309	338
Do. at 650° C.	AEG3C1	291	295
Do. at 700° C.	AEG3D1	282	347



* Values variable; see authors' reply to discussion, pp. 433-453.

FIG. 3.—Outside of 4-Inch Diameter Nickel Steel Bar.

Results on 4-Inch Diameter Bars.—Further pieces of the 4-inch diameter bars were oil-quenched in mass from 840° C. and



* Values variable; see authors' reply to discussion, pp. 433-453.

FIG. 4.—Centre of 4-Inch Diameter Nickel Steel Bar.

tempered in mass at 300°, 400°, 600°, and 650° C. Results on these pieces together with those obtained on the material when normalised in mass at 840° C., oil-hardened in mass at 840° C., and oil-hardened in mass at 840° C. and tempered in mass at 500° C. and 700° C. (see Preliminary Investigation) are given in Tables X., XI., and XII. (See graphs, Figs. 3 and 4.)

TABLE X.—*Tensile Tests on 4-Inch Bars. (Test Mark, AEF.)*

Heat Treatment.	Outside of Bar.						Centre of Bar.					
	Limit of Proportionality. Tons per Square Inch.	Yield Stress. Tons per Square Inch.	Ultimate Stress. Tons per Square Inch.	Modulus of Elasticity $\times 10^{-6}$. Lbs. per Square Inch.	Extension. Per Cent.	Reduction of Area. Per Cent.	Limit of Proportionality. Tons per Square Inch.	Yield Stress. Tons per Square Inch.	Ultimate Stress. Tons per Square Inch.	Modulus of Elasticity $\times 10^{-6}$. Lbs. per Square Inch.	Extension. Per Cent.	Reduction of Area. Per Cent.
Normalised in mass at 840° C. .	27.5	29.5	44.6	28.9	27.0	51.0	23.8	27.5	45.0	28.2	26.0	43.0
Oil-hardened in mass at 840° C.	10.7	42.3 ¹	53.3	29.5	20.0 ²	41.0	10.7	47.0 ¹	57.7	29.4	16.0 ²	32.0
Oil-hardened in mass and tempered in mass at 300° C. .	24.9	44.3 ¹	61.3	29.3	17.6	49.5	20.0	...	59.7	28.1	10.4	33.6
Do. at 400° C.	29.9	52.3 ¹	58.8	29.1	16.0	51.0	25.3	49.8 ¹	58.3	29.2	16.8	42.8
Do. at 500° C.	36.2	40.3 ¹	53.7	29.1	26.0	56.0	32.2	38.8 ¹	54.4	28.9	24.0	49.0
Do. at 600° C.	30.0	35.8	48.6	29.2	26.4	56.5	28.8	33.4	49.8	29.2	25.6	54.5
Do. at 650° C.	25.9	39.6	48.3	29.5	26.4	63.0	23.75	...	47.6	29.4	24.8	58.5
Do. at 700° C.	27.0	36.2	48.5	28.9	30.0	64.0	24.8	31.8	47.5	29.3	31.0	62.0

¹ Small.² Close to gauge mark.

TABLE XI.—Notched-Bar Results on 4-Inch Bars. (Test Mark, AEF.)

Heat Treatment.	Energy absorbed in Foot-Pounds.							
	Outside of Bar.				Near Centre of Bar.			
	First Notch.	Second Notch.	Third Notch.	Average Value.	First Notch.	Second Notch.	Third Notch.	Average Value.
Normalised in mass at 840° C. . .	25.6	29.2	26.6	27.1	24.0	25.8	27.2	25.7
Oil-hardened in mass at 840° C. . .	17.3	17.0	16.6	17.0	13.3	11.3	11.4	12.0
Oil-hardened in mass at 840° C., and tempered in mass at 300° C. . .	10.5	11.1	10.4	10.7	13.9	11.7	11.2	12.3
Do. at 400° C. . .	16.6	15.1	14.8	15.5	17.4	13.2	13.2	14.6
Do. at 500° C. . .	32.4	34.3	35.7	34.1	26.9	27.8	25.0	26.6
Do. at 600° C. . .	60.2	58.2	57.0	58.5	41.7	42.7	35.8	40.0
Do. at 650° C. . .	59.4	52.7	50.7	54.2	47.1	45.9	45.7	46.2
Do. at 700° C. . .	51.9	57.3	64.3	57.8	55.1	47.5	50.0	50.9

TABLE XII.—*Brinell Hardness Tests (4-Inch Bars), from Tests on Fractured Notched-Bar Pieces. (Test Mark, AEF.)*

Heat Treatment.	Near Outside of Bar.				Average Value.	Near Centre of Bar.		Average Value.
Normalised in mass at 840° C. .	201				201	203		203
Oil-hardened in mass at 840° C.	258				258	250		250
Oil-hardened in mass and tempered in mass at 300° C. .	(A)		(B)			(A)	(B)	
Do. at 400° C.	272	277	351	385	321	256	274	265
Do. at 500° C.	269	269	282	305	281	259	277	268
Do. at 600° C.	253				253	258		258
Do. at 650° C.	241	250			245	219	238	228
Do. at 700° C.	230	214			222	215	217	216
	218				218	218		218

(A) One end of test-piece.

(B) Other end of test-piece.

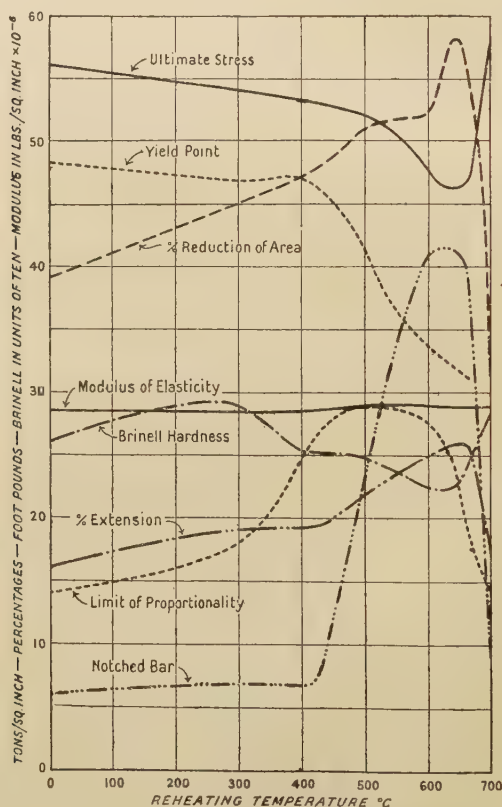


FIG. 5.—Outside of 7-Inch Diameter Nickel Steel Forging.

Results on 7-Inch and 10-Inch Bars.—These bars were both turned from the nickel-steel pinion forging (ACM, Table I.). The heat treatments on each size were as follows :

Piece 18 inches long, normalised in mass at 840° C.

Piece 20 inches long, oil-hardened in mass at 840° C.

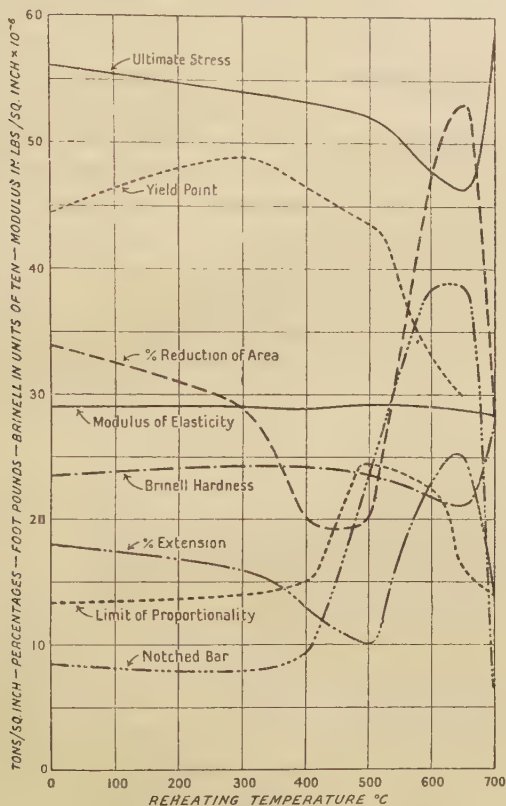


FIG. 6.—Centre of 7-Inch Diameter Nickel Steel Forging.

Test-pieces were cut from the centre and outside of each piece. Test-pieces from the oil-hardened sample were tempered (as test-pieces) at 300°, 400°, 500°, 600°, 650°, and 700° C.

The tensile, notched-bar, and Brinell hardness test results for the 7-inch diameter bar are shown in Tables XIII., XIV., and XV., while the same results for the 10-inch diameter bar are recorded in Tables XVI., XVII., and XVIII. (See graphs, Figs. 5 to 8.)

TABLE XIII.—*Tensile Tests on 7-Inch Piece Turned from Nickel Steel Pinion Forging. (Test Mark, ACM8.)*

Heat Treatment.	Outside of Bar.						Centre of Bar.					
	Limit of Proportionality. Tons per Square Inch.	Yield Stress. Tons per Square Inch.	Ultimate Stress. Tons per Square Inch.	Modulus of Elasticity $\times 10^{-6}$. Lbs. per Square Inch.	Extension. Per Cent.	Reduction of Area. Per Cent.	Limit of Proportionality. Tons per Square Inch.	Yield Stress. Tons per Square Inch.	Ultimate Stress. Tons per Square Inch.	Modulus of Elasticity $\times 10^{-6}$. Lbs. per Square Inch.	Extension. Per Cent.	Reduction of Area. Per Cent.
Normalised in mass at 840° C. .	17.0	35.6	42.5	29.4	30	54	16.6	35.5	44.3	29.5	28	49
Oil-hardened in mass at 840° C. .	13.9	48.3 ¹	56.1	28.5	16	39	13.4	44.4 ¹	51.7	29.0	18	34
Oil-hardened in mass and tempered as test-pieces at 300° C.	17.9	46.8 ¹	54.1	28.5	19	45	13.9	48.8 ¹	54.6	29.1	16	29
Do. at 400° C. .	24.9	47.1 ¹	53.3	28.5	19	47	14.9	46.6 ¹	53.2	28.8	13	20
Do. at 500° C. .	28.8	41.6 ¹	52.2	29.0	22	51	24.4	43.7 ¹	49.7	29.2	10	20
Do. at 600° C. .	27.8	33.8 ¹	47.8	29.0	25	52	22.5	33.0 ¹	47.7	29.0	23	47
Do. at 650° C. .	21.9	31.8	46.3	28.7	26	58	15.9	29.8	46.3	28.7	25	53
Do. at 700° C. .	13.9	...	57.3	28.9	17	30 ²	13.9	...	59.6	28.4	14	28

¹ Yield small.² No definite yield.³ No yield.

TABLE XIV.—*Notched-Bar Test Results from 7-Inch Diameter Bar Turned from Nickel Steel Pinion Forging.*

Heat Treatment.	Energy absorbed in Foot-Pounds.							
	Outside of Bar.				Centre of Bar.			
	First Notch.	Second Notch.	Third Notch.	Average.	First Notch.	Second Notch.	Third Notch.	Average.
Normalised in mass at 840° C.	22.0	21.1	22.3	21.8	15.0	13.8	14.5	14.4
Oil-hardened in mass at 840° C.	4.9	7.3	5.9	6.0	9.4	9.3	6.8	8.5
Oil-hardened in mass and tempered (small pieces) at 300° C.	5.8	7.0	7.7	6.8	7.3	7.5	8.7	7.8
Do. at 400° C.	6.4	7.3	6.5	6.7	9.7	9.7	8.2	9.2
Do. at 500° C.	24.0	22.4	21.9	22.8	24.3	23.6	22.5	23.5
Do. at 600° C.	48.1	36.5	38.5	41.0	36.3	38.6	39.7	38.2
Do. at 650° C.	41.4	43.2	39.1	41.2	37.0	38.2	41.0	38.7
Do. at 700° C.	9.0	7.4	7.5	7.9	8.5	5.7	5.1	6.4

TABLE XV.—*Brinell Hardness Tests on Broken Notched-Bar Test-Pieces from 7-Inch Diameter Bars Turned from Nickel Steel Pinion Forging. (Test Mark, ACM8.)*

Heat Treatment.	Outside of Bar.			Centre of Bar.		
	(A)	(B)	Mean.	(A)	(B)	Mean.
Normalised in mass at 840° C.	180	179	180	190	190	190
Oil-hardened in mass at 840° C.	267	256	261	237	234	235
Oil-hardened in mass and tempered as test-pieces at 300° C.	298 248	360 253	290	236	249	242
Do. at 400° C.	260	249	254	249	235	242
Do. at 500° C.	250	247	248	228	238	233
Do. at 600° C.	223	225	224	217	217	217
Do. at 650° C.	225	230	227	208	215	211
Do. at 700° C.	300 315	263 264	285	273 248	304 273	274

(A) and (B) represent the two ends of the notched-bar test-piece.

TABLE XVI.—*Tensile Tests on 10-Inch Nickel Steel Pinion Forging. (Test Mark, ACM5.)*

Heat Treatment.	Outside of Bar.						Centre of Bar.					
	Limit of Proportionality. Tons per Square Inch.	Yield Stress. Tons per Square Inch.	Ultimate Stress. Tons per Square Inch.	Modulus of Elasticity $\times 10^{-4}$ Lbs. per Square Inch.	Extension, Per Cent.	Reduction of Area. Per Cent.	Limit of Proportionality. Tons per Square Inch.	Yield Stress. Tons per Square Inch.	Ultimate Stress. Tons per Square Inch.	Modulus of Elasticity $\times 10^{-4}$ Lbs. per Square Inch.	Extension, Per Cent.	Reduction of Area. Per Cent.
Normalised in mass at 840° C. .	23.7	27.2	41.4	28.9	30	51	20.4	24.2	40.0	29.7	22	33 ¹
Oil-hardened in mass at 840° C.	18.8	...	50.5	27.8	22.4	54	13.9	...	42.6	28.4	28	54
Oil-hardened in mass and tempered as test-pieces at 300° C. .	22.4	...	50.2	29.0	27	54	19.1	...	42.8	29.1	26	55
Do. at 400° C.	23.9	...	50.3	28.7	25	55	19.9	...	43.3	29.3	26	54
Do. at 500° C.	31.4	33.9	48.2	28.7	26	58	21.5	27.9	43.0	29.4	29	56
Do. at 600° C.	24.1	...	45.6	29.3	28	63	16.1	...	41.1	28.8	32	61
Do. at 650° C.	14.4	39.0	44.7	29.4	30	61	13.4	33.8	41.5	28.9	31	59
Do. at 700° C.	14.9	52.8 ²	74.2	28.9	7	12	13.2	53.6 ²	63.2	28.9	16	25

¹ Signs of "flaw" in test-piece.² Small yield.

TABLE XVII.—*Average Notched-Bar Test from 10-Inch Nickel Steel Pinion Forging. (Test Mark, ACM5.)*

Heat Treatment.	Energy absorbed in Foot-Pounds.							
	Outside of Bar.				Centre of Bar.			
	First Notch.	Second Notch.	Third Notch.	Average.	First Notch.	Second Notch.	Third Notch.	Average.
Normalised in mass at 840° C. . . .	25·8	22·3	25·1	24·2	29·1	29·1	29·2	29·1
Oil-hardened in mass at 840° C. . . .	19·7	17·5	17·0	18·1	36·1	35·0	35·8	35·7
Oil-hardened in mass and tempered as test-pieces at 300° C.	22·0	20·2	25·3	22·5	30·7	33·2	31·7	31·9
Do. at 400° C. . .	24·0	26·0	27·0	25·7	37·5	39·0	37·1	37·9
Do. at 500° C. . .	44·2	36·7	41·2	40·7	42·0	48·4	52·2	47·5
Do. at 600° C. . .	47·2	54·7	52·1	51·3	47·9	52·3	52·6	50·9
Do. at 650° C. . .	51·1	50·3	42·3	47·9	40·8	40·6	36·3	39·2
Do. at 700° C. . .	7·2	5·8	5·9	6·3	3·5	3·7	4·1	3·8

TABLE XVIII.—*Brinell Hardness Numbers on Notched-Bar Test-Pieces, 10-Inch Nickel Steel Pinion Forging. (Test Mark, ACM5.)*

Heat Treatment.	Outside of Bar.			Centre of Bar.		
	(A)	(B)	Mean.	(A)	(B)	Mean.
Normalised in mass at 840° C. . . .	179	180	180	174	179	177
Oil-hardened in mass at 840° C. . . .	255	237	246	190	190	190
Oil-hardened in mass and tempered as test-pieces at 300° C. . . .	230	232	231	198	197	197
Do. at 400° C. . .	246	243	245	194	199	196
Do. at 500° C. . .	220	216	218	196	193	194
Do. at 600° C. . .	215	213	214	191	188	189
Do. at 650° C. . .	207	203	205	188	192	190
Do. at 700° C. . .	276	285	280	279 273	315 327	298

(A) and (B) represent the two ends of the notched-bar test-piece.

The results of all the tests have been plotted in Figs. 1 to 8 as follows :

Diameter of Bar. Inches.	Test-Pieces from Outside of Bar.	Test-Pieces from Centre of Bar.
2	Fig. 1	Fig. 2
4	„ 3	„ 4
7	„ 5	„ 6
10	„ 7	„ 8

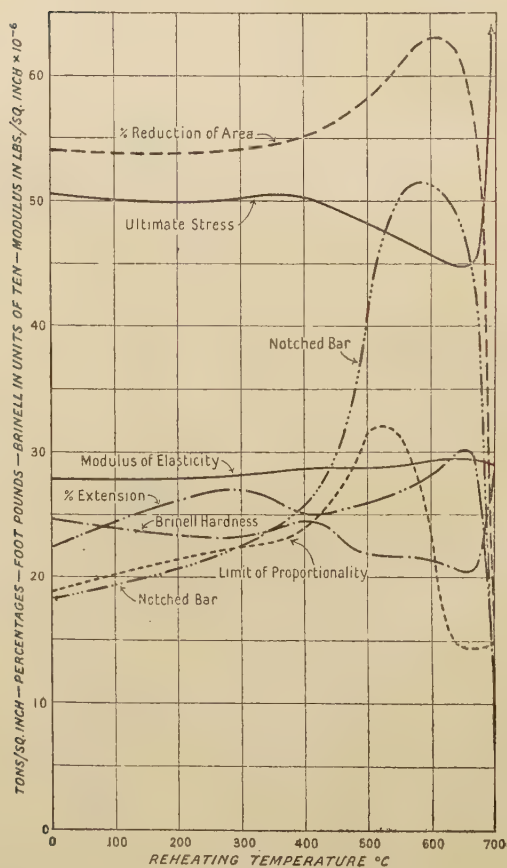


FIG. 7.—Outside of 10-Inch Diameter Nickel Steel Forging.

Curves have been drawn for the following physical properties, showing their variation with the reheating temperatures for tempering :

Limit of proportionality.

Yield stress.

Ultimate stress.

Modulus of elasticity.

Percentage extension.

Percentage reduction of area.

Brinell hardness.

Energy absorbed in fracture
(Izod notched-bar test).

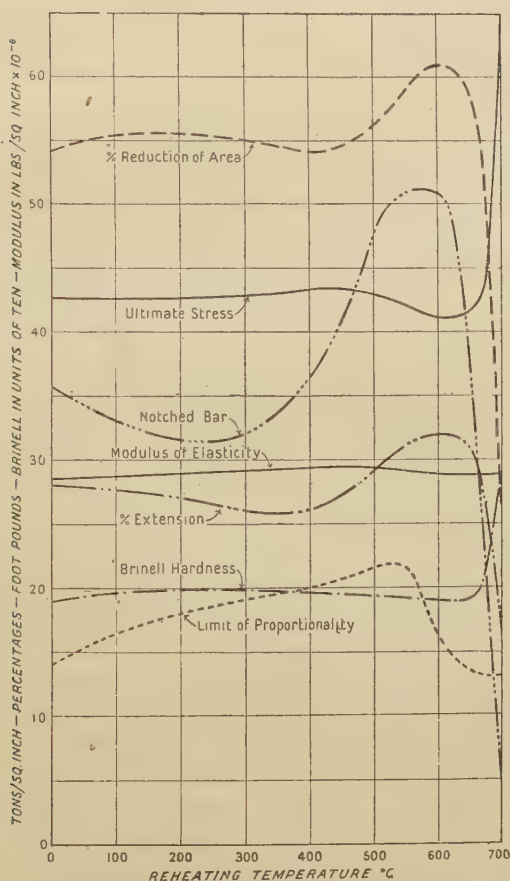


FIG. 8.—Centre of 10-Inch Diameter Nickel Steel Forging.

MICROSCOPICAL INVESTIGATION.

The microstructure of the specimens, typical of each heat treatment used, has been examined for each size of bar, and in each case specimens from the outside and the centre of the bar have been investigated.

The material used was taken from broken Izod impact test-pieces. The face polished was parallel to the axis of the original bar or forging, and therefore parallel to the direction of rolling or forging; the material was etched with a 1 per cent. solution of nitric acid in alcohol. Photomicrographs of a representative selection of test-pieces are shown in Figs. 9 to 28 (Plates XXV. to XXVIII.).

Two-Inch Bars.—Figs. 9 to 13 (Plate XXV.) show the structure developed in the 2-inch bars by different heat treatments. Fig. 9 shows the structure of the normalised bar. Fig. 10 shows the structure of the outside of the quenched bar, while Figs. 11 and 12 show the changes in this structure produced by tempering at 500° C. and 700° C. No well-defined martensite is produced on quenching; the structure obtained is confused, largely troostitic in character, and some grains etch considerably more rapidly than others. On tempering, the material becomes more difficult to etch until the tempering temperature reaches 500° C.; with higher temperatures no difficulty is experienced. The structural changes produced by tempering up to 500° C. are not easily seen; at this temperature the sorbite becomes distinctly granular, as shown in Fig. 11, while at 650° C. the change is slightly more pronounced. Fig. 12 shows material tempered at 700° C. In this case the Ac_1 range has been entered and cementite has been partially redissolved with the formation of new crystals, the growth of which has just commenced.

The structure of the centre of the same bar shows that the material there has not been hardened; the rate of cooling has not been sufficient to prevent the formation of a ferrite network. Fig. 13 represents the quenched material and illustrates this feature very closely. On tempering, changes somewhat similar to those produced in the outside of the bar take place.

Four-Inch Bar.—Figs. 14 to 16 (Plate XXVI.) show the structure

of the 4-inch oil-hardened bar. Fig. 14 shows the structure of the outside: the photograph was taken with a specimen tempered at 300°C ., but this is not essentially different from material as quenched. The formation of a ferrite network has been suppressed by quenching; the structure consists of sorbite or granular pearlite, which can be resolved quite readily at a higher magnification. The cementite is already granular, and tempering at 650°C . produces only slight coarsening of the structure.

The quenching effect on the centre is even less severe. Fig. 15 shows that a considerable amount of ferrite has separated in the form of a network, surrounding grains of sorbite or granular pearlite. Fig. 16 shows the same structure under a higher magnification.

Seven-Inch Bar.—Fig. 17 shows the normalised 7-inch bar. Fig. 18 shows the outside of the oil-hardened piece. Separation of ferrite has not been completely prevented, and a network has begun to form; the structure of the sorbite or granular pearlite is relatively coarse. Tempering causes only a slight change with coarsening of this structure until a temperature of 700°C . is reached (Fig. 19, Plate XXVII.). At this temperature the Ac_1 range has been entered, and the cementite begins to redissolve, and if the material be quenched from this temperature it is found to have hardened. After such quenching, those portions in which solution of the cementite still exists present a very confused structure, while at the same time small areas appear that are structureless under the magnification used, and are probably martensitic. This would account for the great increase in hardness and strength after quenching from this temperature, since the specimens used for the tempering experiments, except in the case of 4-inch diameter bars, were always sufficiently small to be satisfactorily hardened by quenching in water from above the Ac_1 point.

The centre of the piece shows a well-defined ferrite network, and the carbide is present in the form of granular or lamellar pearlite, as illustrated in Figs. 20 and 21. The presence of lamellar pearlite indicates a relatively slow rate of cooling through the A_1 transformation range. Tempering at 500°C . does not appreciably alter the structure, which is still pearlitic, but it becomes more completely granular at 650°C . Tempering at

700° C. again causes a partial solution of carbide, which is illustrated in Fig. 22.

Ten-Inch Bar.—Fig. 23 (Plate XXVII.) shows the outside of the normalised 10-inch bar. Owing to the longer time of soaking necessary for uniform heating of the larger mass of metal, the structure is much coarser than that of the smaller pieces. Figs. 24 and 25 (Plate XXVIII.) show the outside of the oil-hardened bar. The structure is coarse and a distinct ferrite network occurs; patches of very dark-etching sorbite or troostite appear, which seem to be associated with rather mild quenching conditions. They occur also in the centre of the quenched 4-inch bar (Fig. 15, Plate XXVI.), and to a slight extent in the quenched 7-inch bar (Fig. 20, Plate XXVII.). Some of the dark-etching areas are quite unresolved under high powers of the microscope, but areas in which the structure is not so fine also exist, and some of these can be seen in Fig. 25: all stages between very coarse and very fine appear to be represented. The appearance suggests that the eutectoid transformation has taken place with varying speed: the dark areas have been formed by a rapid transformation of austenite to ferrite plus cementite, while the coarse areas have been formed by a slow transformation. The structure might be the result of some undercooling through the normal transformation range, followed by recalescence to the normal temperature. When the change occurred it would then commence very rapidly, giving rise to fine sorbite or troostite, and the heat evolved in the transformation would raise the steel to the true transformation temperature; the result would be that the rate of precipitation of ferrite and cementite would decrease, and therefore the size of the structure would increase until this point was reached, after which the change would proceed only slowly and give a coarse structure. With more rapid rates of cooling, recalescence to the normal transformation temperature could not occur, and the "normal" structure would never be obtained. On tempering at higher temperatures the dark-etching areas disappear, as shown in Fig. 26.

Fig. 27 shows the centre of the 10-inch oil-hardened bar. The material consists of ferrite and granular or lamellar pearlite. The amount of free ferrite is not much less than that in the normalised bar, and the effect of the oil-hardening treatment on

this part of the bar is small. This micrograph, representing material tempered at 300°C ., shows the ferrite network and traces of black etching sorbite or troostite. Fig. 28 shows the material tempered at 650°C . In this material, resolution of the carbide is nearly complete after heating at 700°C . for thirty minutes, but all the ferrite is not transformed.

SUMMARY OF RESULTS.

Mechanical Tests.—In making any comparisons between the results of the mechanical tests, it should be borne in mind that the 7-inch and 10-inch bars were machined from the same pinion forging, but that the 4-inch and 2-inch both differed slightly in composition from the former (p. 387).

When full weight is given to this consideration, the results still show that complete hardening of the steel was never attained during the investigation; even in pieces 2 inches in diameter, the quenching effect was insufficient to give great hardness. In this size of bar, the strength after quenching was only about 60 tons per square inch at both the outside and the centre, but this rose¹ to about 80 tons per square inch on tempering at 300°C ., and subsequently fell as the tempering temperature was raised, until, after tempering at 650°C ., it was little stronger than normalised material.

A bar 4 inches in diameter behaved in a similar manner, but the effect of the initial quenching was not so great, the strength being about 53 tons per square inch at the outside, and 58 tons per square inch at the centre; this rose¹ slightly to about 60 tons per square inch on tempering at 300°C ., and fell to about 48 tons per square inch on tempering at 650°C .; the normalised material had a tensile strength of about 45 tons per square inch.

In the pieces 7 inches and 10 inches in diameter, the strength was not increased by tempering the hardened pieces, which were not greatly affected by this process, unless the temperature exceeded 500°C . The 7-inch bar was strengthened by quenching

¹ In the authors' reply to the discussion (pp. 433-453) experimental results are given which show that the strength obtained in quenched bars of this size is liable to wide variations. In the light of the further work, the results here discussed must be considered as relating to individual bars, and not to average results obtained for specific properties of the material.

both at the outside and the centre, the effect at the outside being greater than at the centre. The 10-inch piece was appreciably affected at the outside by quenching, but the effect at the centre was very small. In the latter case, the strength of the centre was increased from 40 tons per square inch in the normalised material to 42·6 tons per square inch in the quenched piece ; on tempering at 650° C. the strength fell to 41·5 tons per square inch. It will be seen, therefore, that quenching had but a small effect on the tensile strength of this steel if the thickness of the material was 10 inches, and at the centre of a 10-inch bar the effect was negligible.

The elongation of quenched bars was usually small ; it increased at the higher tempering temperatures, but appreciable increase in strength was not obtained without loss of elongation.

The most striking results were obtained from the notched-bar tests ; the quenched material possessed a low notched-bar figure compared with the normalised steel : tempering at temperatures up to 400° C. reduced the figure slightly, but higher temperatures in all cases caused a considerable improvement, a value greatly exceeding that of the normalised material being obtained in all cases with tempering temperatures of 600° C. and 650° C.

This increase in the notched-bar figure could be obtained with heat treatments that gave little or no improvement in the tensile properties of the material ; the improvement in the notched-bar figure was very considerable in both the 7-inch and 10-inch pieces.

Microscopical Examination.—The indications of the micro-structure emphasise the conclusions that may be drawn from the results of the mechanical tests—viz. that the properties that could be obtained in small pieces of this steel, by hardening and tempering, could not be expected in larger masses. In the case of the smallest bar used, the diameter of which was only 2 inches, it was found impossible to obtain complete hardening—i.e. a wholly martensitic structure—in any portion of the material, while at the centre of a bar of this size it was not possible, by oil-quenching, to suppress the formation of a ferrite network, and the advantages of the maximum refinement of structure could not therefore be obtained.

The effect of heat treatment on the structure and properties of the steel was quite marked, in so far as the outer portions of

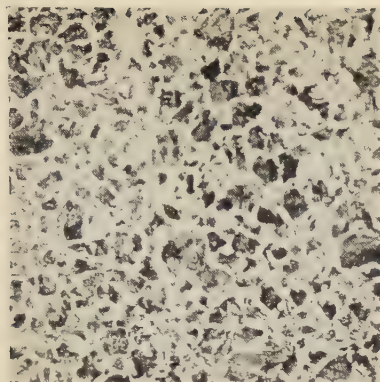


FIG. 9.—2" diameter bar. Outside :
normalised. $\times 150$.

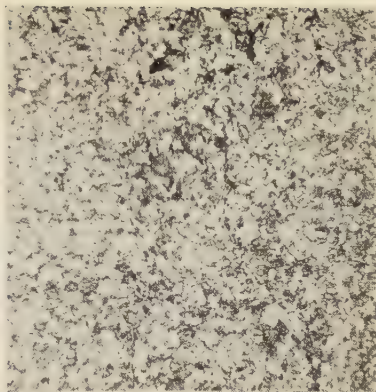


FIG. 10.—2" diameter bar. Outside :
oil-hardened. $\times 150$.

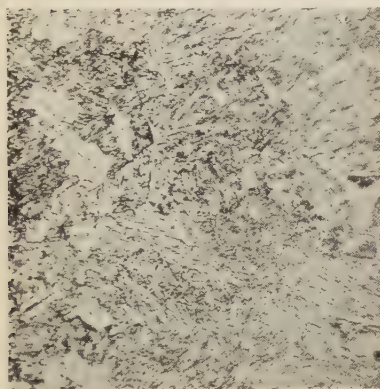


FIG. 11.—2" diameter bar. Outside :
oil-hardened and tempered at 500°C .
 $\times 500$.

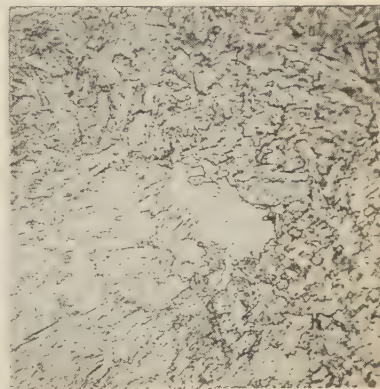


FIG. 12.—2" diameter bar. Outside :
oil-hardened and tempered at 700°C .
 $\times 500$.

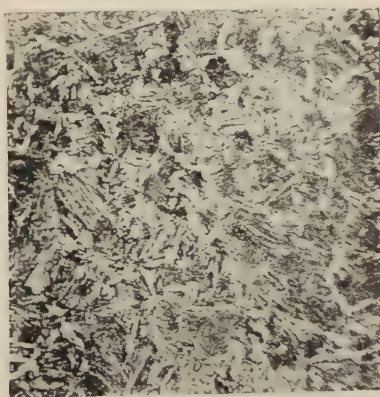


FIG. 13.—2" diameter bar. Centre :
oil-hardened. $\times 500$.

NOTE :—Figs. 9-13 are reproduced $\frac{2}{3}$ original size.

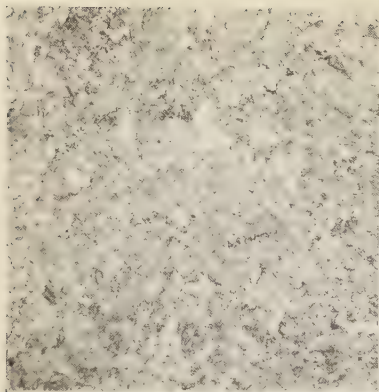


FIG. 14.—4" diameter bar. Outside :
oil-hardened and tempered at 300°C.
× 150.

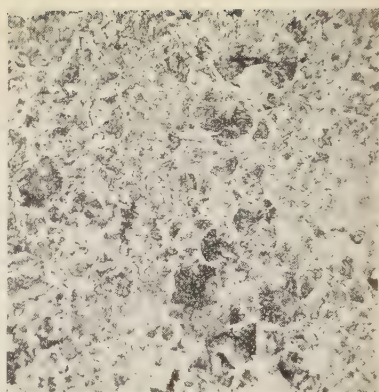


FIG. 15.—4" diameter bar. Centre :
oil-hardened and tempered at 300°C.
× 150.

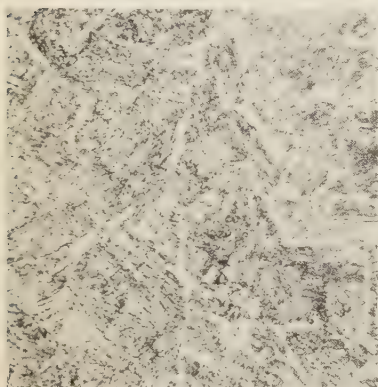


FIG. 16.—4" diameter bar. Centre :
oil-hardened and tempered at 300°C.
× 500.

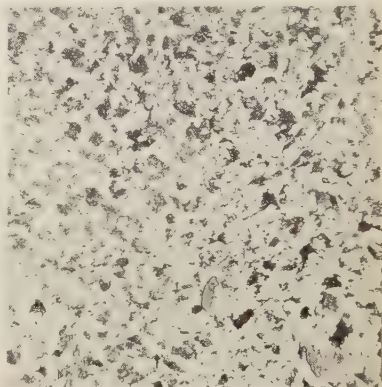


FIG. 17.—7" diameter bar. Outside :
normalised. × 150.



FIG. 18.—7" diameter bar. Outside :
oil-hardened. × 150.

NOTE :—Figs. 14–18 are reproduced $\frac{2}{3}$ original size.

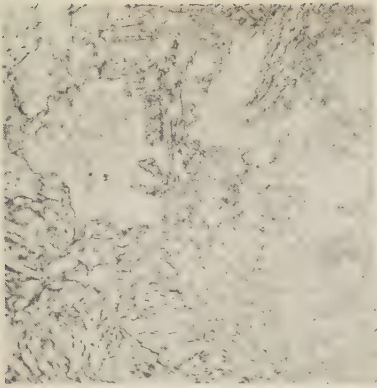


FIG. 19.—7" diameter bar. Outside:
oil-hardened and tempered at 700°C.
× 500.

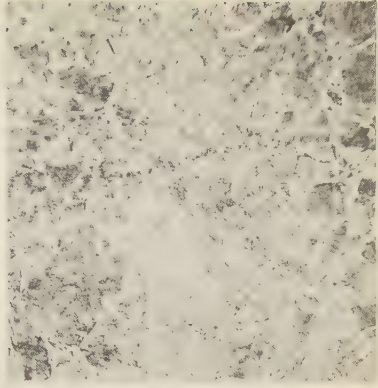


FIG. 20.—7" diameter bar. Centre:
oil-hardened. × 150.



FIG. 21.—7" diameter bar. Centre:
oil-hardened. × 500.

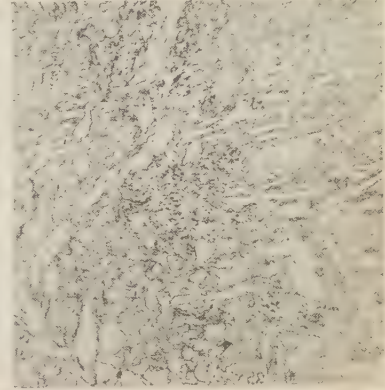


FIG. 22.—7" diameter bar. Centre:
oil-hardened and tempered at 700°C.
× 500.

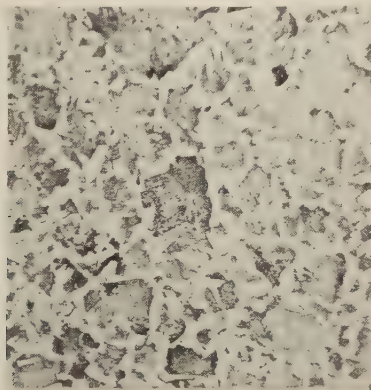


FIG. 23.—10" diameter bar. Outside:
normalised. × 150.

NOTE:—Figs. 19–23 are reproduced 3/4 original size.

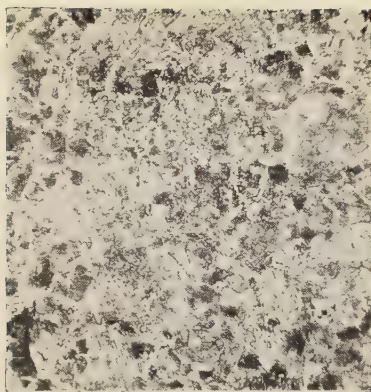


FIG. 24.—10" diameter bar. Outside:
oil-hardened and tempered at 300°C.
× 150.

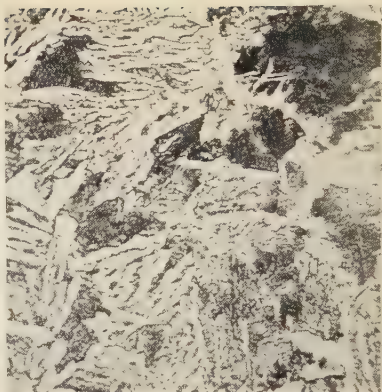


FIG. 25.—10" diameter bar. Outside:
oil-hardened and tempered at 300°C.
× 500.

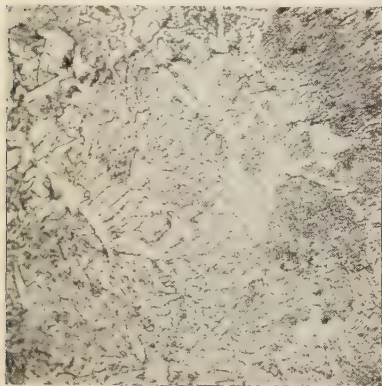


FIG. 26.—10" diameter bar. Outside:
oil-hardened and tempered at 650°C.
× 500.

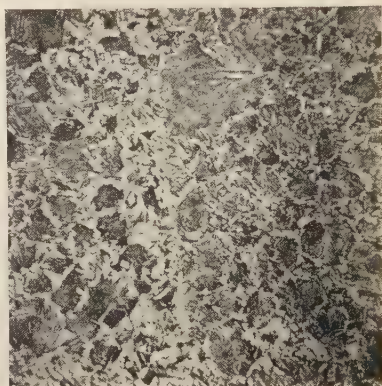


FIG. 27.—10" diameter bar. Centre:
oil-hardened and tempered at 300°C.
× 150.

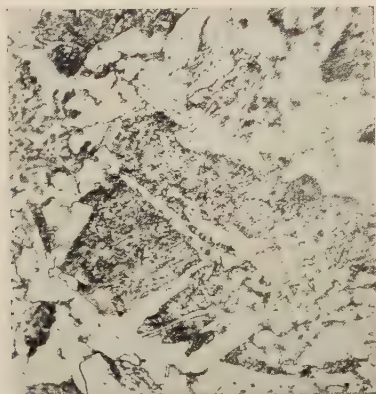


FIG. 28.—10" diameter bar. Centre:
oil-hardened and tempered at 650°C.
× 500.

NOTE :—Figs. 24–28 are reproduced $\frac{2}{3}$ original size.

the material were concerned, even in the case of the largest pieces tested, whose diameters were 10 inches, although in a bar of this size the effect was not very great. In the centre of the bars the effect was much less than at the outside, and in the case of a bar 10 inches in diameter the centre was little different, either in microstructure or mechanical properties, from the normalised steel.

The work described in the present paper has been carried out in the Engineering and Metallurgical Laboratories of the National Physical Laboratory. It has involved the collaboration of a number of investigators besides those named in the title of the paper; these include particularly Dr. D. Hanson, Mr. J. D. Grogan, and Mr. P. L. Thorpe. The authors desire to express their thanks to the Engineering Co-Ordinating Research Board for permission to publish the results of the investigation.

DISCUSSION.

Mr. J. H. S. DICKENSON (Sheffield) said the importance of this work to the special steel industry, supposing that it could be accepted as trustworthy and accurate, needed no emphasis. The data given in the paper were results which had been determined at the National Physical Laboratory—the national home of scientific investigation in this country—at the request of a Government Department. Consequently, if those who were concerned with the manufacture of large nickel steel forgings did not agree with them, it was necessary that they should express their views, and express them very clearly indeed. If the data given in the paper were acceptable they would be useful for reference, and would be welcomed, but he was afraid there were some very serious faults, both in the scheme of the investigation and in the actual results obtained, which made that impossible.

At the outset he would like to refer to the first paragraph, in which it was said that the investigation arose out of a series of failures of pinions of relatively large size in the double reduction gears of marine steam turbines. It was well known that a few years ago there had been quite an epidemic of such failures. He was perhaps more free to express an opinion about that because, no doubt by good fortune, his own firm had been free from that trouble. Meetings of steel-makers and shipbuilders were held to discuss those failures, and he believed that ultimately they were generally considered to be due to mechanical causes, and not to faults in the steel. He would like Dr. Rosenhain to clear up that first paragraph, which implied that there was something wrong in the heat treatment of the forgings which had led to those failures.

The authors referred to an investigation which had been carried out by a Steel Research Committee of the Institution of Automobile Engineers working in conjunction with the Society of Motor Manufacturers and Traders. That Research Committee issued, in 1920, a report which gave a large amount of very valuable data regarding the mechanical properties produced by heat treatment in typical automobile steels. He thought that the steel industry as a whole had never become properly aware of the existence of that report, copies of which could still be obtained from the Secretary of the British Engineering Standards Association. In the course of the work the Committee carried out tests on twenty different steels, the data being condensed into a series of graphs, in colours, which were published along with all the results on which the curves were based. From those graphs engineers using steel for aircraft or automobile construction, or indeed any work requiring steel forgings and bars of sizes up to about 3 inches or 4 inches in diameter, could obtain accurate data for de-

signing and reference purposes. As far as he knew, that data had never been controverted, but the Committee, when selecting the various steels, were very careful to specify the part of the ingot from which the bars were to be rolled, and they took steps to ensure uniformity of the material which was to be subjected to various forms of treatment. The principal results were given in the form of "tempering graphs" and "mass graphs." The tempering graphs were of the type shown in the present paper—a series of bars being oil-hardened or water-hardened and then individually tempered at various temperatures from about 200° C. up to, or beyond, the critical range. Each graph was based on three sets of bars treated and tested by different investigators in order to eliminate the personal factor. Not unnaturally, the Committee had to deal with rather considerable discrepancies in some cases, but they were discrepancies which, taking them as a whole, it was possible to explain and eliminate. The irregularities in the plotted curve obtained from the results of one investigator were generally balanced by the opposite "wobbles" in another investigator's curve, and finally a smooth curve, in which confidence could be placed, was made possible. The "mass graphs" were similarly prepared from the results returned by three different investigators, but in those the mechanical test results obtained after some given heat treatment were plotted against the diameter of the bar. As a typical graph he might mention that of nickel-chromium steel from which round bars of $\frac{1}{16}$ inch, $1\frac{1}{8}$ inch, $2\frac{1}{8}$ inches, and 3 inches diameter were rolled. In that case the investigator received test-bars of each diameter which were all heat-treated alike by oil-hardening at 820° C., followed by tempering at 600° C., a very common treatment for that type of steel. The various mechanical test figures—tensile strength, reduction of area, energy absorbed in the impact test, and so on—were then plotted, with the diameter of the bar as the horizontal co-ordinate, and the resulting graph showed at a glance the influence of mass, over a range appropriate to automobile engineering, on the mechanical properties resulting from that particular treatment.

Such a graph was totally missing from the present paper, although if the authors had obtained comparable data suitable for the purpose from 3 per cent. nickel steel bars ranging in diameter from 2 inches up to 10 inches, they would have produced a most valuable graph for reference purposes.

Now, after the Automobile Steels Report was issued he (Mr. Dickenson) was asked, as Chairman of the Executive Sub-Committee which drew up the report, to present a paper to the Institution of Automobile Engineers dealing with some of the salient features in the results of the investigation. Dr. Rosenhain took part in the ensuing discussion, and along with some very kind remarks he offered the Committee both advice and admonition. He was sure Dr. Rosenhain would not mind if he asked him whether he had applied to the present paper the advice which he had then given, in which he said, "When the

results of an investigation, even if it is not called a research, are examined and discrepancies are found, the most useful thing to do is to find out what is the cause of these discrepancies." The present paper contained some very serious and unexplained discrepancies to which he would now draw attention.

In the first place, the authors had actually used three different steels in an investigation to determine the effect of mass in the heat treatment of 3 per cent. nickel steel. They were roughly of the same analysis, but of different casts. They used one steel for the 2-inch bars, another for the 4-inch bars, and yet another steel for the two larger diameter bars. The analyses of those three steels differed so considerably as regarded carbon, chromium, and manganese that they were not strictly comparable. If bars of the same size from each steel were to be given similar heat treatment they could not be expected to have the same mechanical properties. Therefore there was no material in the paper with which to build a mass graph, and the paper could not be considered very helpful without a graph such as he had described. The steel should have been from the same cast for all diameters of bar. Even if the three steels, coming from different casts, had nominally the same analysis, one could still not depend on getting the same results from them after similar treatment; but in the present case the variations in composition were considerable.

Turning now to the 7-inch and 10-inch bars, which were cut from the same pinion forging, he thought the authors should have given some details to show what part of the pinion each sample came from. He could produce a large pinion forging such that if a 10-inch bar were cut from the central axis, and a 7-inch bar from the outer part, they would differ considerably in carbon content, and consequently not be comparable for the present purpose.

The paper did not contain that information, but he suggested to the authors that they should have cut complete transverse sections for metallographic examination across the pinion, and thus have found whether the forging came from the lower or upper parts of the original ingot, and whether it was higher or lower in carbon towards the central axis than towards the outside. If the pinion were lower in carbon on the central axis than towards the outside, as it would be at the lower end of the ingot, and if the larger diameter bar came from the central part, the effect would be to increase the apparent mass influence. On the other hand, if the 10-inch bar came from the upper central zone of higher carbon content, the effect would be to mask the mass influence. He asked the authors to state whether steps were taken to find out whether the pinion were uniform in composition throughout, and, generally, whether the 7-inch and 10-inch bars could be accepted as comparable pieces of steel.

That was not all. There were some peculiarities, of which the authors might have an explanation, in the results themselves. Why did 2-inch diameter nickel steel bars show such a marked rise in the

tensile strength on tempering at 300° C. when the larger diameter bars did not show it? Surely, if that were a fact it was a very remarkable one, and should receive some explanation. But, so far as he knew, it was not a fact. He had carried out many such tempering series on 3 per cent. nickel steel, and he had never found properly hardened 2-inch diameter bars of 3 per cent. nickel steel rise 15 or 20 tons per square inch in tensile strength on tempering at 300° C., nor, indeed, any rise at all.

It might be due to some peculiarity in the way the test-bars had been hardened. There, he thought, lay the explanation, because the confession was made that there was "a fairly considerable variation" in the Brinell results after oil-hardening and before tempering at all. It was actually said that they varied from 282 to 364. He ventured to say that in regular works heat treatment of small-diameter nickel steel bars it was not usual to get such variations on similar samples.

The range of tensile strength represented by that variation was from about 60 tons up to about 80 tons—about the extent of the apparent rise on tempering at 300° C. He suggested that this remarkable result was obtained because the test-bars were not properly oil-hardened—a conclusion to which he saw no alternative.

In any case the 4-inch bars did not show such a rise. Was that because of some difference in the steel? If that were accepted as an explanation, how could the effect of mass on the results of heat treatment be determined by comparing those two steels?

Dr. D. HANSON (National Physical Laboratory) said he might perhaps be allowed to deal with one or two points which Mr. Dickenson had raised. In the first place, Mr. Dickenson, referring to the opening paragraph of the paper, had stated that it had yet to be shown that failures in pinions were due to defects in the material. Had he read the paragraph carefully he would have appreciated that no such suggestion was made there. The investigation had been undertaken in order to ascertain what properties might reasonably be expected in large pinions, because that information had not been at the time available. On examining those large masses of steel, structures were found which were not obtained in smaller masses, and it had been desired to know what particular structure corresponded to any particular size of bar. He thought the net result was that no real hardening could be expected in large forgings such as were used for the pinions in double reduction gearing—and that was a very important thing to know definitely. The paper was quite conclusive on that point, because it showed that in a bar 10 inches in diameter, the hardening effect was only very slight on the outside and inappreciable in the centre. He thought that supported the view which had been arrived at, namely, that the failures of those pinions had not in general been due to any particular weakness of the steel itself.

Then Mr. Dickenson had referred to the variability of composition.

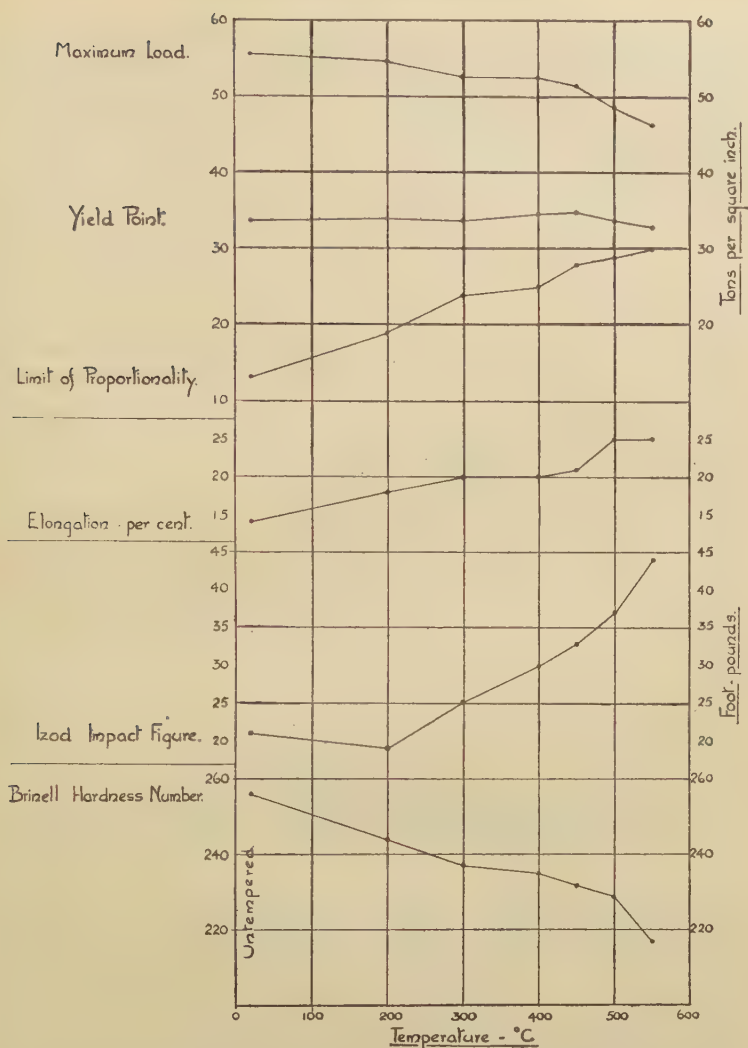
It was true that the different bars had not exactly the same composition, and that did make it impossible to draw certain deductions which would otherwise be possible, and those deductions had not been drawn; but certain very definite conclusions had emerged from the work, which were of very great importance. For example, it was shown that the properties of quite moderate-sized pieces could not be very greatly improved by heat treatment, and some very definite idea was given of the particular qualities which could be expected in any size varying from 2 inches to 10 inches thick. The experiments showed that although the steels varied in composition a little, the general result which emerged was not different from one to the other. Those main conclusions were not really affected by the actual differences in composition.

Mr. J. A. JONES (Woolwich) said that he would like to add something with regard to the curves in Figs. 1 and 2. The rise in ultimate stress shown in the diagrams would be very remarkable if it were a genuine effect, but it was fairly evident that discrepancies in the tests had given this form to the curve. It was difficult to get uniform material for tests from large sections of nickel steel, as the material was so susceptible to mass effect; but it was essential, when comparative tests were to be carried out on material tempered at varying temperatures, that the sections, as hardened, should possess identical properties. It seemed from the figures given in Table IX. that this condition was not fulfilled, nor were the differences allowed for in drawing conclusions. The Brinell hardness number bore a fairly constant relation to the maximum load, therefore, in order to study the curve of ultimate stress, he thought it would be agreed that variation of the Brinell hardness could be taken as a measure of the variation in the ultimate stress. A comparison of the hardness of the same specimens before and after tempering could be obtained from Tables VIII. and IX., thus:

Brinell Hardness at the Centre of the Bar.

Tempering Temperature. Degrees Cent.	Before Tempering. (Table IX.)	After Tempering. (Table VIII.)	Decrease in Hardness.
300	364	355	9
400	340	312	28
500	319	246	63
600	309	219	90

The authors' figures therefore showed a fall of hardness after tempering, a result which was in accordance with general experience, but which was not shown in the diagram.



Two Hours' Treatment at Each Temperature.

Dimensions of pieces oil-hardened and tempered: $5 \times 1\frac{1}{2} \times 1\frac{3}{4}$ inches.

Chemical Composition.

	Per Cent.		Per Cent.
C	0.390	S	0.042
Si	0.070	P	0.020
Mn	0.320	Ni	3.760

FIG. A.—Nickel Steel Oil-Hardened from 850° C. Effect of Tempering at Different Temperatures.

He had obtained the curves given in Fig. A while investigating a steel similar in composition to those employed by the authors. In those tests care was taken that all the bars had the same hardness after oil-hardening and before tempering. In the authors' tests the variation of hardness was so great that he did not think that the smooth curves which they had given were justifiable.

With reference to the variation in composition of the steels, the first two contained chromium, while the third, which contained no chro-

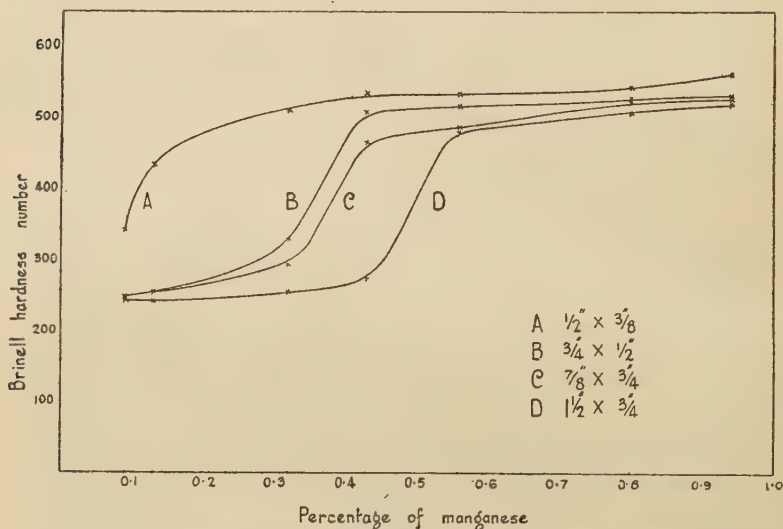


FIG. B.—Effect of Mass in Heat Treatment. Influence of manganese on the hardening of nickel steel bars of different dimensions, quenched in oil. C, 0.4 per cent. Ni, 3.9 per cent.

mium, was much higher in manganese than the others. The diagram (Fig. B) showed the effect of variation of manganese content on the properties of a 4 per cent. nickel steel, with special reference to the influence of mass. Thus small variations in manganese content had a marked effect on the depth of hardening which might be obtained in steels of various sizes, and the presence of small percentages of chromium produced similar results. The authors, however, gave no indication of the extent to which variation in composition influenced the properties of the bars and modified the effect of mass.

Mr. H. BREARLEY (Member of Council) said that Mr. Dickenson had covered so thoroughly the possible grounds of criticism in relation to the paper that there was very little left for him to say, except to give his whole-hearted support to the remarks made by Mr. Dickenson.

He could not understand how anyone could start to determine the influence of mass, where presumably mass was to be the only variable, and then introduce independent variables into the material itself.

He would particularly like to speak about the results obtained on the 2-inch bars, because he was in a position to give some information about the effect that might be expected from a variation in composition amounting to, say, 0.2 per cent. of chromium. If two identical steels, varying in composition only in respect of chromium, the variation being about 0.2 per cent., were oil-hardened in the form of 2-inch round bars, a difference in tensile strength of between 10 and 20 tons in the hardened bars might be found, so that unless the authors in the present case were certain that variations in composition were going to cancel out somehow or another, the comparative value of the results obtained was at least doubtful.

He noticed also that in carrying out the tempering operation for the larger bars a small piece was used which had been cut out of a hardened bar. It was said that some preliminary tests had convinced the authors that in the tempering operation mass produced no serious differences. That also, he thought, was a dangerous assumption to put forward for general acceptance. It was many years since he personally had been engaged in operations relating to armour manufacture, but he remembered having failed to obtain coincident results on laboratory pieces, which were necessarily small, and factory pieces—that was to say, large plates themselves—when considering the effect of tempering operations. Ultimately, differences were traced down to the rate of heating; in the laboratory that would be carried out on the small piece relatively quickly, and in the factory on the very large pieces it must necessarily be carried out very slowly. It would be observed that, after tempering, the pieces had been water-quenched, and that the tempering temperatures had been pushed so high that they were just inside the hardening range. A glance at the curves would show that on tempering at 700°C . the material had begun to harden again. As the paper dealt with the effect of mass, he did not think it could be claimed that in quenching out a piece of material from within the hardening range, it did not matter whether a small piece were used or whether the work were done on a 10-inch bar.

The Brinells on the hardened bars themselves showed very wide variations, but amongst the results presented in the paper came the surprising statement that the hardened 2-inch bar had a tensile strength of about 60 tons only. More startling still was the claim that when the hardened bar—or an identical bar—had been tempered to 300°C ., its tensile strength rose to above 80 tons. After reading that statement, and looking at the curves, he had come to the conclusion that either a great discovery or a serious mistake had been made. He had been making curves of the kind reproduced in the paper, and carrying out complete forms of heat treatment of steels of different compositions, for twenty years. He had examined hundreds of different

kinds of alloy steels, many of them closely related in composition to those now under discussion, but he had never seen an example where, on tempering a hardened bar (which really had been hardened) at 300°C ., the tensile strength had risen appreciably. He thought that almost invariably in steels of that class the tensile strength fell on tempering. In looking through his records, he found that a hardened 2-inch bar of steel of this composition generally had a tensile strength of between 85 and 95 tons, and that tempering the material at 300°C . generally reduced that tensile strength about 5 tons. When the Steel Research Committee associated with the Automobile Industry was formed, it was laid down by the main Committee that the heat treatment of the steel bars should not be carried out by anybody in any way connected with the steel industry, and for two years the Executive Committee who supervised the work endeavoured to get the bars heat-treated by people who were not accustomed to heat treatment work. At the end of that period they had to go to the main Committee and say that the work could not be done under the stipulated conditions. In carrying out heat treatment it was easy to say all that was necessary was to heat a piece of material to 850°C . and quench it out in oil. It was not difficult to calibrate a pyrometer and put it into the furnace, but it was by no means such an easy thing to know when the piece of material placed in the furnace ought to come out, and it seemed to him that the surprising results recorded in the paper were due to lack of experience in carrying out heat treatment.

Dr. W. H. HATFIELD (Sheffield) confessed that the opening sentence relative to reduction gearing pinions had appeared to him to be unnecessary. The critical period in the particular problem to which reference was made was long past, and he thought it was rather unnecessary to drag the subject forward again. However, any little annoyance which he might have felt had now vanished, because the statement in the first sentence of the paper had been of great value in eliciting from Dr. Hanson an unqualified statement of the view held at the National Physical Laboratory, namely, that the trouble which had occurred with regard to reduction gearing pinions was not due to inherent defects in the steel. It was very gratifying to any investigator to have such a statement from an impartial body like the National Physical Laboratory.

Turning to the paper, one felt that the National Physical Laboratory occupied a position of great importance in relation to the industries of the country, and everyone knew that it was doing a lot of extremely good work; but he was compelled in the present instance to associate himself with Mr. Dickenson and Mr. Brearley in the exception which they had taken to some of the data in the paper, resulting from the heat treatment of this nickel steel. Such data were not in conformity with those which had been obtained in his own laboratories. He was quite sure that any investigator connected with the industry would

endorse what previous speakers had said concerning the figures. He was sorry to have to say that, but it was a very serious matter when a Government Department went to a national institution for light on a subject of great consequence to it. It was necessary also that one should observe that the nickel steel with which the authors dealt was really the first high tensile alloy steel introduced, in the sense that in the evolution of steel metallurgy, when the special elements came along, the first special steel to which engineers had settled down had been a nickel steel, and that nickel steel was made in very considerable quantities and also in very large masses in the various special steel works. It was a steel which was completely understood. Investigators knew perfectly well what values could be obtained from that steel in varying mass under different conditions, and it seemed unnecessary for the National Physical Laboratory to devote its valuable time and resources to such work when they could so profitably be employed in the interests of the industry in producing fundamental data which would so much assist the industry.

Dr. Hanson, in speaking of the microstructures, had said they had had to study those microstructures in order to discover what structure corresponded to a particular size of bar. Obviously, in the industry, where large masses of nickel steel were handled, that knowledge was common property. When the National Physical Laboratory, or Woolwich, or any other Government institution, tackled a problem which was of direct consequence to the industry, he thought that those in charge of the investigations might suitably let the industry know that they were conducting the investigations. He felt sure that the several works concerned would invite the investigators to visit them and would show them much information in their possession. It was not that the industrial research laboratories and the firms themselves were at any time unwilling to publish the results of their investigations; it simply was that people engaged in research in the industry were so very busy doing research that they had not time to publish a lot of data which could very usefully be published.

Mr. T. M. SERVICE (Glasgow) said he entirely concurred in the remarks made by Mr. Dickenson, Mr. Brearley, and Dr. Hatfield. When one noted the method of heat treatment, and the discrepancies which took place, it was not surprising that the authors had obtained some strange results. It was said that the difference in the temperature at the ends of the furnace in a distance of 18 inches was 20°C . Would anyone with practical experience of heat treatment allow that in a works? If one had a furnace 50 feet long, and found there was a 20°C . difference between the two ends, one would want to know something about it. On p. 397 there appeared the following: "Oil-hardened in mass. Outside of bar, Brinell hardness 295 and 290"; and at the other end of the bar the figures were 363 and 279. Surely the authors did not regard those results as representative of normal practice?

He thought the trouble had arisen in the method of carrying out the heat treatment.

Mr. T. HENRY TURNER (Birmingham) suggested that the value of the paper would be increased if it were stated exactly how the chemical analyses had been taken. In comparing the physical properties of the inside and outside of such bars after heat treatment it was important that it should be known what differences might be attributable to initial differences in the chemical composition of the bars. Some of the figures, particularly in the preliminary tests, appeared to indicate that considerable differences in chemical composition existed, and segregates could be seen in some of the micrographs.

If the paper were to show the effect of mass in the heat treatment of those steels, surely the easiest manner would have been to have shown a diagram of the cross-section with the Brinell hardness numbers right across it. The Brinell hardness was now sufficiently well understood to convey in that manner valuable data. The practical application of the paper appeared to be that no pinion should be made as large as 10 inches and heat-treated, unless a 2-inch or 3-inch hole were drilled right through the centre. The improved mechanical properties caused by the cooling in the centre during the quenching of such hollow pinions would compensate for the small loss of strength due to the cutting away of the interior metal. .

Colonel N. T. BELAIEW, C.B. (London), drew attention to the authors' statement: "In making any comparisons between the results of the mechanical tests, it should be borne in mind that the 7-inch and 10-inch bars were machined from the same pinion forging, but that the 4-inch and 2-inch both differed slightly in composition from the former. When full weight is given to this consideration, the results still show that complete hardening of the steel was never attained during the investigation." It seemed to him that to a certain extent those words explained why exception had been taken by so many speakers to the results as reported. The fact that the authors of the paper definitely stated that the complete hardening of the steel had never been attained was a very important point. He thought that the title of the paper was a little misleading, and that not only the effect of mass on the heat treatment should be mentioned, but also the effect of the shape. Everyone who had been engaged in the heat treatment of armour plates would say that it was possible to obtain, after any kind of heat treatment, the desired results as to structure and properties, and to a considerable depth. It was always rather difficult to compare the results of laboratory tests with factory tests, but if the volume of oil or water in comparison with the mass of the specimen were taken into consideration, then it was quite possible to obtain the results aimed at in either small or large specimens.

CORRESPONDENCE.

Mr. E. F. LAW (London) wrote that the authors had referred to the results of some investigations which he had brought before the Institute in 1918, and as the authors' conclusions were so fundamentally at variance with his own he could not refrain from one or two comments. He did not wish to go into any unnecessary details, but the authors' results were so extraordinary and so opposed to all previous experience that he would venture to suggest a repetition of their experiments on fresh samples of steel before arriving at any definite conclusions. It was a well-known fact that firms engaged in the treatment of steel had spent very large sums in putting down plant for the treatment of large masses of steel by oil dipping. The practice was carried out daily in those works, and tests of the steels after treatment were almost invariably taken, so that an immense amount of information had been accumulated. Surely it was incredible in these days, when there was not less scientific ability inside the works than outside, that the practice should be continued and so much money expended by a number of firms independently of one another, and in competition with one another, unless the results justified it.

Mr. A. R. PAGE (Birmingham) wrote that as the investigation dealt with one variable—mass—it would have been expected that all the other factors would have been kept constant. While the compositions of the 2-inch and 4-inch bars were the same, within the errors of chemical analysis, those of the 7-inch and 10-inch bars differed considerably, the carbon being 0.05 to 0.06 per cent. lower and the manganese nearly double. It could hardly be said, therefore, that the results obtained on the 7-inch and 10-inch bars were of great value when compared with the other results, even though the paper was obviously not meant to describe a fundamental research.

The most striking results in the paper, however, were those showing the remarkable behaviour of the 2-inch bars on tempering. That a 3 per cent. nickel steel on tempering at 300° C. would increase in tensile strength from 60 tons per square inch in the hardened state to 85 tons per square inch in the tempered state (an increase of 40 per cent.) was certainly a discovery. It had long been known that certain hardened steels when tempered in the lower ranges (100° to 300° C.) increased in hardness and presumably in tensile strength, but that increase up till now had been found to be at the most 10 per cent. Certain chrome steels, high-speed steels, and even plain high-carbon steels had shown this peculiarity, but it was confined as a rule to steels which in the hardened state possessed hardnesses considerably greater than those given by the authors for the 3.5 per cent. nickel steel, viz. about 300.

The explanation of that phenomenon was that those hardened steels retained a certain amount of austenite, which on tempering broke down into martensite, with a consequent increase in hardness.

It did not seem possible that a steel such as that described in the paper (0.3 per cent. carbon and 3.5 per cent. nickel) would retain enough austenite after hardening, for the latter, on tempering, to cause an increase in strength of about 40 per cent. Surely a hardened steel which contained so much austenite as to produce that phenomenon would contain a considerable amount of martensite, and then the hardness in the hardened condition would certainly be much higher than 300. Most steels which on hardening remained practically entirely austenitic, and which on tempering became almost entirely martensitic, did not increase in strength by 40 per cent. Had the authors any direct evidence at all that those bars contained any austenite in the hardened state?

Considering the hardnesses before and after tempering, given in Tables VIII. and IX., the figures for the centre of the bar were :

	Before Tempering.	After Tempering.
As hardened	301	286
To be tempered at 300° C.	364	355
" " 400° C.	340	312
" " 500° C.	319	246
" " 600° C.	309	219
" " 650° C.	291	211
" " 700° C.	282	210

There was a big difference in the hardnesses of the bars after hardening (282 to 364). It surely could not be argued that the results after tempering were of any value in those circumstances.

It seemed to him (Mr. Page) that insufficient care had been taken to see that all the bars of the same mass were hardened to the same degree; the results were therefore very misleading.

Mr. L. W. SCHUSTER (Manchester) wrote that a point which stood out prominently in the paper was the comparatively high hardness value of the 7-inch and 10-inch test-pieces when quenched from 700° C. after hardening at 840° C. It was to be noted that not only were the Brinell figures higher than those of the pieces of smaller cross-section when similarly heat-treated, but that they were higher than when pieces of those sizes, or even most of the smaller pieces, were quenched from 840° C. alone. Similarly the highest ultimate strength and the lowest impact value were obtained with those large test-pieces when tempered at 700° C. He would be glad if the authors would give

an explanation of that behaviour, which could hardly be attributed altogether to the small difference in chemical analysis.

Mr. T. M. SERVICE (Glasgow) wrote further that the results obtained by Dr. Rosenhain and his collaborators differed so greatly from those recorded by the Automobile Engineers Steel Research Committee, and also those obtained in mass in everyday commercial work, that some explanation was necessary to account for the variations. The composition of the steels used for the 2-inch and 4-inch bars was almost identical, and could therefore be usefully compared. The steel used for the 7-inch and 10-inch bars differed in composition considerably from the others, and must therefore be placed in another class, and compared against themselves. That difference in the composition of the steel of the smaller and larger sections rendered abortive the purpose of the paper, viz. to show the effect of mass on the heat treatment of nickel steel.

A comparison of the 2- and 4-inch sections showed that oil-hardening at 850° C. and tempering in mass at 300° C. raised the ultimate tensile strength of the outside of the 2-inch bar 24·4 tons, and the inside 18·1 tons per square inch, over that obtained by oil-hardening alone, while oil-hardening in mass at 840° C. and tempering at 300° C. raised the ultimate tensile strength of the outside of the 4-inch bar 8 tons, and the centre 2 tons per square inch, over that obtained by oil-hardening alone. Again, in the case of the 2-inch bar oil-hardened at 850° C. and tempered at 700° C. in mass, the ultimate tensile strength of the outside was raised 7·3 tons, and the centre 11·7 tons per square inch, over that obtained by oil-hardening and tempering at 650° C.; the 4-inch bar, oil-hardened in mass at 840° C. and tempered at 700° C., showed no increase in the ultimate tensile strength over that obtained by oil-hardening and tempering in mass at 650° C., either at the outside or the centre of the bar. In addition, oil-hardening in mass and tempering as test-pieces at 700° C. only raised the ultimate tensile strength of the same 4-inch steel bar 1·7 ton at the outside and 2·9 tons per square inch at the centre. At a temperature of 650° C. the maximum softening effect was obtained after oil-hardening.

It was common knowledge of those accustomed to carrying out heat treatment that for it to be successful the pieces must be heated uniformly and the temperature raised progressively, so that if the operation, when raising the temperature to 700° C., were stopped at, say, 650° C. and cooled out, the effects due to that temperature would be obtained. If that be accepted as an axiom of good heat treatment, could the authors explain why in the case of the 2-inch bar the ultimate tensile strength was raised 7·3 tons at the outside and 11·7 tons at the centre, while that of the 4-inch bar tempered as a test-piece was raised only 1·7 ton at the outside and 2·9 tons per square inch at the centre, if the same temperature, 700° C., had been uniformly attained in each case?

With regard to the raising of the ultimate tensile strength by tempering at 300° C. after oil-hardening, and particularly as that rise was much more pronounced in the 2-inch bar than in the 4-inch bar, the same or a greater increase would have been expected in the case of the 1½-inch bars used by the Automobile Engineers Steel Research Committee. Dr. Rosenhain was a member of that Committee, and he (Mr. Service) understood that the National Physical Laboratory took a part in the heat treatment of the various bars used. Could Dr. Rosenhain explain why the peculiarity described was not detected by him or any other member of the Committee who heat-treated corresponding bars?

In comparing the 7- and 10-inch bars, the following irregularities would be found :

Oil-hardening at 840° C. and tempering at 300° C. :

Outside. No increase or decrease in ultimate tensile strength.

Centre. An increase of 2·9 tons per square inch over the results obtained by oil-hardening at 840° C.

The Brinell hardness figures on the outside required some explanation. It was stated that the mass oil-hardened at 840° C. gave Brinell numbers 267 at the *A* end and 256 at the *B* end, which was consistent. But on tempering the test-piece the Brinell figures were : *A* end 248/298 and *B* end 253/360. The Brinell figures gave a fair indication of the ultimate tensile strength. Were the authors satisfied that, if the 300° C. tempering heat had been uniform in every part of the test-piece, such irregular results were to be expected—*i.e.* at the *A* end of the bar the ultimate tensile strength varied from 54·5 tons to 65·5 tons, while at the *B* end it varied from 55·6 tons to 79 tons? The 10-inch bar oil-hardened at 840° C. and tempered at 300° C. showed no increase in ultimate tensile strength nor irregularities in Brinell hardness, either at the outside or at the centre, over that obtained by simple oil-hardening. As the 7- and 10-inch bars were made from the same steel, could the authors explain why the 7-inch bar behaved so peculiarly? Further, in the case of the 7-inch bar oil-hardened and tempered at 700° C., the increase in ultimate tensile strength, outside, was 11 tons per square inch, and centre, 13·3 tons per square inch, over that obtained when tempered at 650° C. The 10-inch bar, outside, gave an increase of 29·5 tons per square inch, and the centre, 21·7 tons per square inch. Again, the question could only be asked, was the 700° C. the same in both cases?

He was not clear as to the meaning intended in the statement : "In the case of the larger masses it was desired to avoid tempering in the mass, on account of the expense of preparing test-pieces from the large number of samples which would be required; such machining would have added greatly to the cost of the investigation." In the tables it was stated that the bars were oil-hardened in mass, then tempered as test-pieces. Having considerable experience in machining this class of steel, he had never found that machining in the oil-hardened

state was practicable, let alone cheaper, than when the same operation was carried out in the tempered state. Would the authors explain their methods more fully? He could not agree with the statement made in the latter part of the same paragraph that annealing test-pieces gave similar results to those obtained by heating in the mass. No account was taken of the time element, which was an important item in mass heating.

Dr. W. ROSENHAIN, F.R.S. (Teddington), wrote in reply that in view of the discussion which had taken place on the paper as originally presented to the Institute, the publication of the paper had been, at his request, withheld and the preparation of the present reply delayed, until further experimental work could be carried out. This experimental work, with the exception of the hardness testing and preparation of test samples for which Mr. R. G. Batson of the Engineering Department was responsible, has been carried out, not by the authors of the original paper, but by two other members of the staff of the Metallurgy Department of the National Physical Laboratory, namely, Messrs. C. H. M. Jenkins and A. J. Murphy, and he (Dr. Rosenhain) wished to express his indebtedness for the large amount of care and interest which they have taken in carrying out this work. Dr. Rosenhain, however, wished to take full personal responsibility for the present reply.

Discussion had centred mainly on the inference which could be drawn from the figures and curves as originally published, that in the case of materials 2 in. and 4 in. in diameter, the hardness and tensile strength of the heat-treated and tempered nickel steel, of the kind described in the paper, was higher after tempering at 300° C. than in the condition as quenched in oil at 850° C. It may be pointed out at the outset that this particular inference constitutes a side-issue as far as the main purpose of the paper is concerned. It does not in any way affect the principal conclusions arrived at as to the effect of increasing diameter on the possibility of hardening a nickel steel of this type. It was, however, made the occasion for criticising the methods and results of the work described in the paper as a whole.

The results concerning the effect of tempering at 300° C. as contained in the original tables and figures of the paper are undoubtedly remarkable, but the authors regarded them as matters of minor interest from the point of view of the paper, and did not feel justified in pursuing these matters further in view of the limitations imposed upon them in regard to time and expenditure in connection with the research in question. In view of the importance, however, which has been attached to them in the discussion, it has been thought desirable to investigate this point more fully. It is not, of course, at all surprising that such a fuller investigation should reveal facts which had not previously been apparent to the authors of the original paper nor, it would seem, to others having expert knowledge of the heat treatment of alloy steels.

Some time had elapsed between the completion of the experimental

work and the presentation of the original paper to the Institute. During that time the plant used in the investigation had been largely dismantled and disposed of for other purposes. It has therefore been quite impossible to repeat the original experiments in their entirety, as it would, perhaps, have been most satisfactory to do. All that has been possible, therefore, has been to carry out a series of quenching and tempering tests on bars 2 in. in diameter, using furnaces different from those employed in the original research and much smaller quenching baths (32 gallons capacity), although the same kind of oil was employed. It has, accordingly, been impossible to carry out tensile tests, and the whole of the confirmatory work which has been done since the discussion on the paper took place relates to determinations of hardness by means of the Brinell and the Vickers hardness measuring machines on sections cut in various ways from hardened and tempered bars. In view, however, of the well-known close relationship between tensile strength and Brinell or other hardness numbers in heat-treated steel, the confirmation available from the hardness tests now to be described is, it would seem, adequate. It may be said at once that the results of the confirmatory work which has now been carried out are amply sufficient to show that the results as originally published are accurate and reliable records of correctly performed experiments, but that the number of those experiments was not sufficient to establish the average behaviour of the material, which, as it now appears, is extremely sensitive and erratic in its response to hardening and tempering in certain conditions. To this extent, therefore, it is necessary to alter the conclusion suggested by the original figures in a manner which is indicated below.

In view of the suggestion contained in the discussion of the original paper that the conditions under which the samples of steel had been quenched and tempered had not been such as to produce normal and satisfactory results, he (Dr. Rosenhain) felt that it was desirable to investigate the effect of various factors in the conditions of quenching and tempering upon steel of this type, as well as the effect of a slight variation in the composition of the steel itself, in order to ascertain the precise effect of minor differences of procedure upon the results obtained, and also in order to determine the range of variability which might be expected when the utmost care was used in the heat treatment of the material. The general results obtained may be summarised by saying that with one exception even considerable variations in the procedure do not appear to affect appreciably the average results obtained. On the other hand, the range of variability found in every sample of steel of this type which has, since the discussion, been quenched and tempered, is so great that it is difficult to express the results in terms of averages which have any real significance. So marked are these variabilities that any attempt to smooth them out by rejecting extreme values can only lead to misleading interpretations. As it happens, certain of the results contained in the original paper are near the extreme limits of

this variability, and it is only by fuller and more detailed investigation that this fact has been discovered. It certainly cannot be ascribed to any lack of correct procedure in the original experiments.

The material used in the series of experiments now being described consisted of two lengths of 2 in. diameter rolled bar, one being part of the material described as AEG in the table of chemical analyses given on p. 387 of the original paper. The second (marked APQ) was also a 2 in. diameter bar, from a different maker, and had the following composition :

	%
Carbon	0.33
Silicon	0.17
Sulphur	0.033
Phosphorus	0.029
Manganese	0.66
Nickel	3.58
Chromium	0.07

It will be seen that in this second steel there is very little chromium, while the manganese content is appreciably higher than in the original steel. It may be pointed out that the difference in composition between the new material, the analysis of which is given above, and the original material AEG is greater than those found, on careful analysis, between drillings taken from different parts of a cross-section of the 4 in. diameter material described in the original paper. In view of the variability of hardness, both in the "as quenched" and "tempered" condition, of specimens of both of these steels, any mean figure of hardness for comparison of the two would be almost meaningless. Specimens of these two steels have, however, been used for comparison in several of the tests which are described in detail below. Although a slight systematic difference between them could be detected, this was not even approximately comparable with the range of variability found in cross-sections of either. The conclusion is in fact fully justified that these two steels, so far as their behaviour under heat treatment is concerned, may be regarded as almost identical, and that therefore the suggestion that segregations in the steel used in the original experiments were mainly responsible for variability of results may be entirely dismissed.

The second point investigated related to the precise effect of quenching temperature upon the resulting hardness of the steel. In the original experiments described in the paper, a range of temperature of some 20° C. was shown to exist between the two ends of 14-in. bars. In the present experiments, bars 14 in. in length were also used, but in this case calibrated thermocouples were inserted in small holes drilled in the specimen, one at each end and one in the middle of the length of the bar. Temperature differences as indicated by these thermocouples never exceeded $\pm 5^{\circ}$ C., so that any effect from variability of quenching temperature could be eliminated. In the experiments made to test the effect of quenching temperature, however, the steel was used in the

form of discs 2 in. in diameter and $\frac{3}{8}$ in. thick, being cross-sections of the 2-in. bars. Specimens of this size were used in order to secure the most uniform degree of hardening, with a view to exhibiting the effect of quenching temperature as definitely as possible. The quenching

*Effect of Temperature on the Hardening of
3 per Cent. Nickel Steel.*

Slices 2 in. in Diameter $\times \frac{3}{8}$ in. Thick.

(Material as used in paper for 2-in. size.)

(For details of the determinations, see Fig. C.)

Quenching Temperature. °C.	—	Average Vickers Hardness No.
750	10 min. soak	591
770	" "	594
790	" "	593
810	" "	597
830	" "	583
850	" "	580
870	" "	574
890	" "	575
910	" "	585
930	" "	576
950	" "	567
810	30 min. soak	577
950	" "	574
<i>Further Material (composition given under Fig. E).</i>		
790	...	551
850	...	548

temperatures employed ranged from 750° C. to 950° C. in steps of 20° C. The results obtained, on a series of hardness impressions made on two diameters (at right angles) of each disc, are reproduced graphically in Fig. C. Even in discs of this comparatively thin section there was an appreciable range of variability of hardness, the numbers in a typical case ranging from 550 to 580 on the Vickers machine scale. There is, however, no systematic difference between the discs quenched at different temperatures, the hardness numbers being comprised between a mean value of 567 for the discs quenched at 950° C. and 591 for that quenched at 750° C. It is obvious, therefore, that minor variations of quenching temperature, of the order of 20° C., can produce no appreciable effect on the hardening of this particular steel. It must be admitted that, in view of the sensitiveness of this steel in regard to other conditions of heat treatment, this result is surprising, but it has been carefully checked and is regarded as entirely reliable. This is

probably due to the fact that under quenching conditions the transformation of the steels which results in hardening occurs at a very low

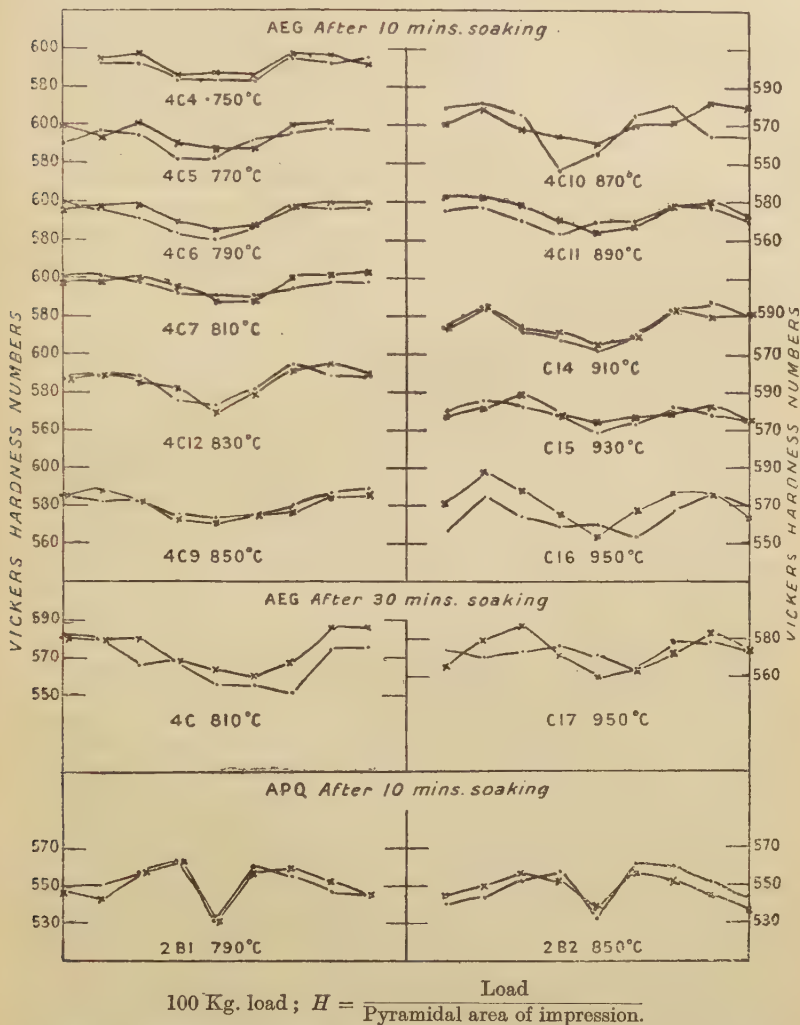


FIG. C.—3 per cent. nickel steel. Vickers diamond pyramid hardness numbers. Oil-quenched after soaking at the temperatures marked. Not tempered.

temperature, and the rate at which this temperature is passed through appears to be unaffected, or only very slightly affected, by the initial

temperature of the steel at the moment of quenching, provided that the steel has been made hot enough to pass through the transformation range on heating. In order to test this point, some actual cooling curves have been taken, using specimens of the AEG steel 2 in. in diameter and 2 in. thick, and rapidly cooled by immersion in a small quantity of oil from a temperature of 1050°C . The transformation point was found at 430°C ., while in the same steel when cooled at the normal rates used for the determination of the thermal arrests, the critical range occurred at 625° to 600°C . Under similar conditions, in an ordinary 0.48 per cent. carbon steel, the transformation during oil-cooling was found to occur at 650°C ., showing a very much smaller amount of depression from the normal value. It is this difference which is probably responsible for the remarkable sensitiveness of the nickel steel to conditions of cooling during quenching, particularly at the lower temperatures of the cooling range.

In the discussion of the original paper considerable stress has been laid on the wide variation of hardness numbers, as shown by the tests on a series of bars in the same condition. This variability of the hardness results was recognised by the authors, and is clearly stated as a variation of from 282 to 364 in the Brinell numbers (see part of p. 397 of the original paper). It was suggested that this variability was an indication of unsatisfactory treatment of the steel. In order to test this point, a considerable number of specimens from both the 2 in. steel bars referred to above have been subjected to quenching and tempering under various conditions. The hardness of the bars thus treated has been carefully investigated by sectioning them in various ways and making a large number of hardness determinations upon the sections. One of these heat-treated bars has been sectioned by machining away in a milling machine one-half of the bar longitudinally, thus exposing a central longitudinal section for examination. In other cases, transverse sections have been cut by means of a machine saw and the surface smoothed by careful machine grinding. Although in every case care was taken to avoid any irregularity in the grinding and to minimise any local heating, it has been suggested that possible irregularity in this process might have caused some of the peculiar results described below. In order to test this point, two lines of experiment were adopted. In one case the bars were split longitudinally and bolted firmly together before heat treatment. This unfortunately proved abortive, since it was found that a certain amount of shallow decarbonisation occurred on the split surfaces, so that hardness determinations subsequently made on those surfaces might be illusory. The other method consisted in removing the ground surface to an appreciable depth by etching with acid, the hardness determinations being repeated after this process. It was found that the irregular hardness distribution as determined on the ground surface was satisfactorily reproduced on the same surface after a layer had been removed by etching. The depth removed in this case was 0.08 in. It may therefore be safely concluded

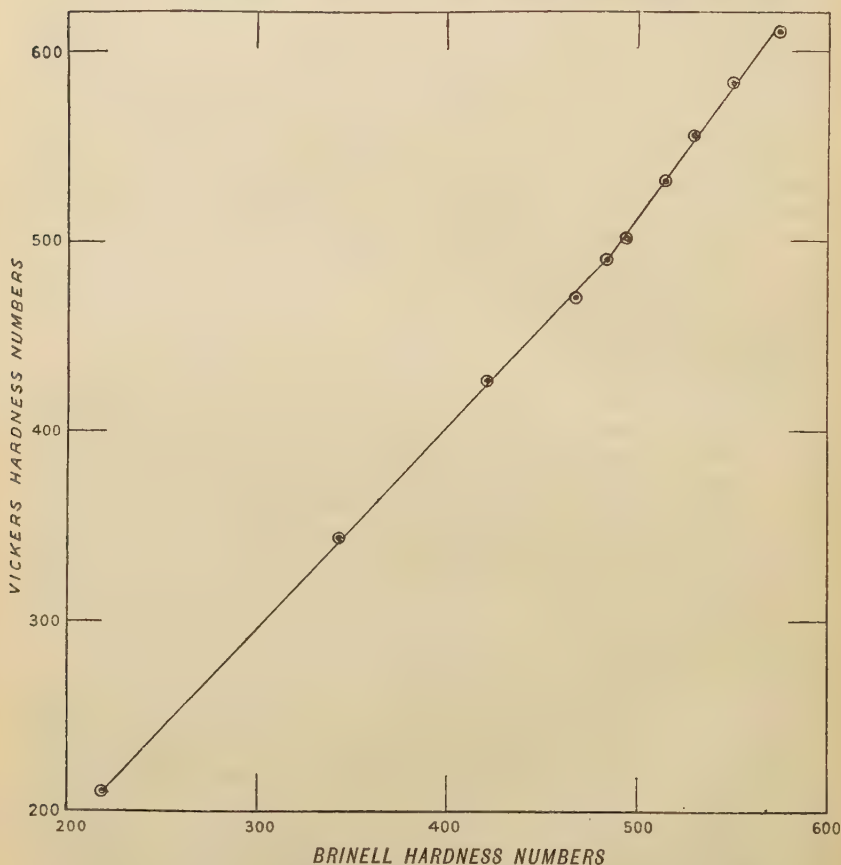
that the irregularities found in the hardness determinations are real and not due to any experimental irregularity.

In order to investigate the variation of hardness across the section of the bar it was necessary to employ a small indenting tool. A ball, 1 mm. in diameter with a load of 30 kg., gives (on homogeneous material) Brinell hardness numbers strictly comparable with the standard ball and load (10 mm. and 3000 kg.) used in the original paper. Owing to the comparatively high hardness numbers obtained in some of the present experiments, the diameters of the small circular impressions could not be measured with the necessary accuracy. For this reason a pyramidal diamond and the Vickers hardness testing machine have been employed. The impression made by this test has sharper edges and the width of the impression can, therefore, be measured with greater accuracy. Hardness numbers are therefore given in terms of the Vickers machine, except in one instance, where, in one of the earlier experiments, a 1-mm. Brinell ball impression was used. For convenience of comparison a graph is appended (Fig. D), which gives the relation, over the range employed in these experiments, between the Vickers hardness numbers and the Brinell numbers.

As a result of these experiments it has been found that variations in the hardness number amounting to as much as 154 units can occur in the most carefully and uniformly quenched piece of nickel steel of this composition whose dimensions are 2 in. in diameter and 14 in. long. As a rule it is found that the hardness is greatest at the end and near the periphery of the specimen and that the centre is the softest, but irregular variations are frequent. This great variability in hardness throughout the cross-section of a single piece of steel of moderate size can only be ascribed to excessive sensitiveness of this particular material to heat treatment. In the present check experiments there can be no question of variability of furnace temperature, even if any importance could be attached to such a cause in view of what has been said above. Care was also taken to see that there was no delay whatever in transferring the specimens from the furnace to the oil quenching bath. Appended are six charts (Figs. E to K, inclusive) showing the distribution of hardness on longitudinal diametral sections of six of these bars. The figures on five of these bars have been obtained, however, by cutting transverse slices and testing the hardness of these along corresponding diameters. On the sixth bar, the hardness tests were made on an actual longitudinal section.

In order further to elucidate the questions raised by the paper and its discussion, a series of experiments has been made in which the exact conditions of quenching the steel have been varied by varying the time of immersion in the oil. In the work described in the original paper this time of immersion was long, the steel bars being generally left in the oil bath overnight after quenching. At the same time they were only held and moved about vigorously in the oil so long as there was obvious and violent action. When this had ceased they were allowed

to drop to the bottom of the bath, which, however, was vigorously agitated by compressed air. There was at that time, and, so far as the discussion on the paper goes, there appears to be up to the present moment, no published knowledge to the effect that such a method of



Values. (Hankins, *Proceedings of the Institution of Mechanical Engineers*, 1926, vol. ii. p. 823; see p. 839.)

Vickers . .	210	344	426	476	490	501	531	555	583	610
Brinell . .	219	344	422	469	485	495	515	530	550	575

FIG. D.—Relationship between Vickers hardness and Brinell hardness numbers.

treatment is other than completely satisfactory. Very similar treatment is, in fact, in industrial use at the present time. In the present series of experiments, however, the bars were held and moved about vigorously in the oil for a specified length of time, and were then withdrawn

Nickel Steel Bar, APQ2C (New Material).

*Chart of Distribution of Hardness on Cross-Sections. Tested on Diameters.
Vickers Diamond Hardness, 100-kg. Load.*

	0.1"	0.3"	0.6"	0.6"	0.3"	0.1"	
	571	553	589	559	557		0.1"
	533	499	431	430	534		1"
							2"
X ₁	554	499	401	447	491	X ₁	
							2"
X ₂	551	484	434	482	491	X ₂	
	487	435	401	461	505		
	516	508	454	480	501		
	552	493	410	480	543		
	555	504	423	497	526		
	575	547	563	553	549		1"
							0.1"

SUPPLEMENTARY DETERMINATIONS.

Further readings taken on a longitudinal section between the positions marked X₁X₁ and X₂X₂:

X ₁ X ₁	553	484	408	466	530
Intermediate	541	488	415	472	533
X ₂ X ₂	527	497	410	475	534

Further readings taken on a cross-section between points marked X₂X₂ after dissolving away 0.08 in. from the surface of the section by means of a mixture of hydrochloric and nitric acids:

541	474	433	485	547
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These readings were taken below a cross-section whose initial values were:

551	484	434	482	491
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FIG. E.

Temperature of quenching, 850° C. Not tempered.

Time of stirring in oil, 15 min., followed by air-cooling.

Average hardness, excluding points 0.1 in. from ends of bar, 486 for 15 min. quenching; determined in 35 positions.

Size of bar, 2 in. diam. × 14 in. long.

Composition:

	%		%
Ni . . .	3.58	Si . . .	0.17
C . . .	0.33	S . . .	0.033
Cr . . .	0.07	P . . .	0.029
Mn . . .	0.66		

Nickel Steel Bar, APQ2D (New Material).

*Chart of Distribution of Hardness on Cross-Sections. Tested on
Diameters whose Relative Positions are given in Diagram.
Vickers Diamond Hardness, 100-kg. Load.*

	0.1"	0.3"	0.6"	0.3"	0.1"	
	511	496	493	495	500	0.1"
						1"
	473	444	429	458	462	
						2"
X ₁	430	397	353	405	424	X ₁
						2"
X ₂	407	375	340	385	410	X ₂
	417	387	340	383	415	
						2"
	413	386	345	385	413	
						2"
	417	382	337	383	420	
						2"
	446	418	385	421	433	
						1"
	463	452	435	447	460	
						0.1"

SUPPLEMENTARY DETERMINATIONS.

Further readings taken on a longitudinal section
between the positions marked X₁X₁ and X₂X₂:

X ₁ X ₁ .	415	384	345	392	423
Inter- mediate }	414	380	343	391	421
X ₂ X ₂ .	415	382	348	376	406

FIG. F.

Temperature of quenching, 850° C. Not tempered.

Time of stirring in oil, 1 min., followed by air-cooling.

Average hardness, excluding points 0.1 in. from ends of bar, 403 for 1 min. quenching; determined in 35 positions.

Size of bar, 2 in. diam. × 14 in. long.

Composition given under Fig. E.

Nickel Steel Bar, APQ2H (New Material).

*Chart of Distribution of Hardness on Cross-Sections. Tested on
Diameters whose Relative Positions are given in Diagram.
Vickers Diamond Hardness, 50-kg. Load.*

0.1"	0.3"	0.6"	0.6"	0.3"	0.1"	
298	280	247	246	246		0.1"
248	229	228	225	227		1"
253	237	227	238	247		2"
259	245	232	245	250		2"
259	250	229	237	263		2"
267	263	230	245	265		2"
266	239	234	250	249		2"
277	271	266	279	297		1"
366	334	308	344	350		0.1"

FIG. G.

Temperature of quenching, 850° C. Not tempered.

Time of stirring in oil, $\frac{1}{2}$ min., followed by air-cooling.

Average hardness, excluding points 0.1 in. from ends of bar, 249 for $\frac{1}{2}$ min. quenching; determined in 35 positions.

Size of bar, 2 in. diam. \times 14 in. long.

Composition given under Fig. E.

Nickel Steel Bar, APQ2G.

*Chart of Distribution of Hardness on Cross-Sections. Tested on
Diameters whose Relative Positions are given in Diagram.*

Vickers Diamond Hardness, 100-kg. Load.

0.1"	0.3"	0.6"	0.6"	0.3"	0.1"	
507	491	476	525	496	0.1"	
485	444	377	461	489	1"	
467	401	358	426	488	2"	
516	461	391	467	516	2"	
494	440	361	458	470	2"	
391	388	361	406	518	2"	
399	395	358	431	504	2"	
479	458	412	420	490	1"	
529	520	507	529	518	0.1"	

FIG. H.

Quenched in oil initially at 50° C.

Temperature of quenching, 850° C. Not tempered.

Time of stirring in oil, 12 min.

Average hardness, excluding points 0.1 in. from ends of bar, 439; determined in 35 positions.

Size of bar, 2 in. diam. × 14 in. long.

Composition given under Fig. E.

*Nickel Steel Bar, AEG4E (Material of Original Paper).**Chart of Distribution of Hardness on Cross-Sections. Tested on Diameters whose Relative Positions are given in Diagram.**Vickers Diamond Hardness, 100-kg. Load.*

0.1"	0.3"	0.6"	0.6"	0.3"	0.1"
579	539	492	547	513	0.1"
527	494	391	467	506	1"
504	449	385	425	476	2"
531	455	372	427	515	2"
529	409	372	390	443	2"
545	437	357	379	427	2"
485	402	444	386	433	2"
518	461	407	440	470	1"
561	517	502	518	527	0.1"

FIG. J.

Temperature of quenching, 850° C. Not tempered.

Time of stirring in oil, 15 min. (bar sufficiently cool to be held in the hand).

Average hardness, excluding points 0.1 in. from ends of bar, 443 for 15 min. quenching; determined in 35 internal positions.

Size of bar, 2 in. diam. × 14 in. long.

Composition:

	%		%
Ni . . .	3.43	Si . . .	0.186
O . . .	0.364	S . . .	0.025
Cr . . .	0.208	P . . .	0.030
Mn . . .	0.425		

Nickel Steel Bar, APQ2A (New Material).

Chart of Distribution of Hardness on Longitudinal Section through Centre of Bar, at Positions given in Diagram.

Note.—Brinell Hardness, 1-mm. Ball, 30-kg. Load.

	0.1" 0.3"	0.6"	0.6"	0.3" 0.1"
0.1"	457	401	412	510 438
0.5"	432	429	404	447 429
	461	420	420	474 471
0.5"	435	421	398	415 438
	474	432	448	477 464
	438	435	385	426 438
1.0"	464	409	385	464 464
	429	426	385	406 429
1.0"	457	383	383	461 464
	435	423	390	415 432
1.0"	471	398	390	467 448
	435	423	382	418 432
1.0"	467	390	401	461 464
	435	432	380	398 441
1.0"	477	441	417	454 471
	435	421	398	404 444
1.1"	457	429	393	454 461
	426	421	388	418 432
0.9"	471	426	383	444 471
	435	415	370	418 435
1.0"	444	438	404	448 471
	421	404	377	412 438
1.0"	457	426	366	420 471
	421	404	363	415 444
1.0"	444	435	366	426 471
	421	401	393	398 438
1.0"	416	404	347	398 426
1.0"	417	404	352	415 429
0.5"	423	417	393	417 426
0.5"	435	432	432	435 435

FIG. K.

Temperature of quenching, 850° C.
Stirred in oil until hand-cold. A portion of bar was removed before tempering.

Figures "as hardened" in roman type.

Figures "tempered 300° C." in italics.

Size of bar, 2 in. diam. × 14 in. long.

Composition given under Fig. H.

and placed on the floor. It has now been found that the length of time during which the bars are held and moved about in the oil affects the resulting mean hardness of the steel to a remarkable extent, and that the highest degree of hardness obtainable with the material is not secured unless the bars are agitated in the oil for several minutes after quenching. Since all vigorous action appears to cease after not

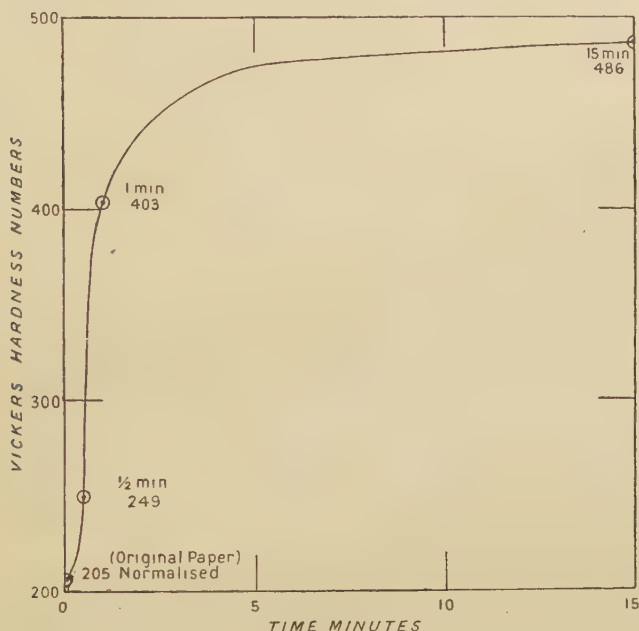


FIG. L.—APQ material. Nickel steel bars, 2 in. in diameter \times 14 in. long. Time of immersion and stirring in cold oil of bars heated to 850°C . This was followed by air-cooling to room temperature. The zero reading is "as normalised."

The values 249, 403, and 486 are averages of thirty-five readings taken on seven cross-sections down the bars, which were quenched for 0.5, 1, and 15 minutes.

much more than twenty seconds of immersion, this effect is surprising. Its general nature is illustrated by the graph, Fig. L, which shows the mean hardness of bars quenched at the same temperature but held in the oil for half a minute, one minute, and fifteen minutes respectively. It will be seen that the curve rises very rapidly between a time of immersion of one-half and one minute, and after that rises much more slowly to the highest figures obtained after fifteen minutes' immersion. It is striking to notice that the mean hardness number obtained after

half a minute's immersion is only 249, while that obtained after fifteen minutes' immersion is as high as 486. It should be mentioned that each of these numbers is the mean value taken from thirty-five impressions in each case. The variability of the hardness number in each of the bars, however, varies in an interesting manner. It is least—the range being 70—in the specimens which have been removed from the oil after half a minute, while in those which have been kept in the oil for one minute and fifteen minutes respectively the range is 136 and 154. It would thus seem that in order to secure full hardening it is necessary to continue the cooling of the steel by agitation in oil for a considerable time, but that when such full hardening is secured it does not in the least follow that it will be more uniform than, or even as uniform as, the hardening obtained from agitation for half a minute in oil. The lack of uniformity in the hardness numbers found in the original paper, therefore, cannot be ascribed to unduly short immersion in the oil. The comparatively wide variation in the hardness actually found in the specimens described in the original paper, which variation is, it may be mentioned, less than that to be found in a single specimen of the present series, must therefore be ascribed in the first place to the irregular variability of the steel itself, due to the sensitiveness already referred to, and partly to the fact that the exact cooling conditions may have varied slightly from bar to bar, as successive bars after comparatively short agitation in the oil were allowed to drop to the bottom. The oil in that case, however, had been agitated by an air-blast, so that one would have anticipated very uniform results in the light of the further experiments now undertaken. It should be mentioned that the bars of larger diameter described in the original paper were quenched by suspension in agitated oil until quite cold.

Soon after the original paper had been discussed, a metallurgist connected with an important steelworks was good enough to send to the authors the results of some hardness tests on quenched nickel steels of approximately the same composition. It is interesting to notice that his Brinell numbers range about a value of 270.

In connection with these measurements of the hardness obtained in 2-in. diameter bars in the condition obtained by quenching in oil from a temperature of 850° C., it is interesting to note that the mean difference between the two varieties of steel used in the present experiments—namely, AEG, as described in the original paper, and the second steel (APQ), whose analysis is given above, after fifteen minutes' agitation in the oil—amounts to about 43 points on the Vickers hardness scale, the actual numbers being 443 for steel AEG and 486 for steel APQ. As mentioned above, these differences are not large compared with the variations found in a cross-section of a single piece of either steel.

A further test was made to ascertain whether a difference of the temperature of the oil, which might result from the successive quenching of a number of bars in the same bath, would materially affect the results obtained. For this purpose a bar was quenched, under otherwise

identical conditions, in a bath of oil previously heated to 50°C . It was held in this oil for fifteen minutes, and the mean hardness found was 439 as compared with 486 when quenched in cold oil. Again, it will be seen that the difference, although appreciable, is not so large as the variations of the cross-section of an individual bar. Since the temperature in none of the experiments can have reached the neighbourhood of 50°C ., this result indicates that variations in the temperature of the oil cannot be held responsible for the variations encountered.

In the discussion of the original paper Mr. J. A. Jones gave some interesting data, obtained at Woolwich, in dealing with the effect of manganese and of dimensions on the hardness obtained on quenching nickel steels of the type here under consideration. One of his figures particularly (Fig. B) shows that for every size of specimen quenched there is a critical range of manganese content which renders the steel exceedingly sensitive to slight variations in regard to the hardness produced by quenching. These observations may be regarded as a very satisfactory confirmation of those described in the present reply. The dimensions of the bars used in the present experiments are larger than any of those mentioned in Mr. Jones' data, but it is quite evident, from the results obtained, that, when quenched from 850°C . in oil, bars of this particular size and material are cooled at a critical rate, so that very slight differences between one bar and another, and even more particularly between different portions of the same bar, either in regard to velocity of cooling or manganese content, possibly also carbon or nickel content, may produce disproportionately large results. It will be noticed that this variability of result was confined in the original paper to the bars 2 in. in diameter, and to a much lesser extent the bars 4 in. in diameter, while the larger bars ranging up to 6 in. in diameter were not affected in this way. It was evident that these larger bars did not approach the critical rate of cooling under the conditions of quenching employed.

Tempering experiments at 300°C . have been carried out on a considerable number of specimens hardened in the investigation here described. In view of the variability of the hardness in the cross-sections of the specimens, it is not surprising to find that the hardness of the material after tempering at 300°C . is also variable, but it is interesting to notice that the variability has been diminished by tempering. Broadly speaking, the results may be described by saying that the tempering at 300°C . tends to reduce the hardness of fully hardened material and *to increase to some extent the hardness of the softer portions of a specimen.*

In five of the charts which accompany the present reply, the figures indicate the Vickers hardness numbers found at the points indicated for specimens as quenched in oil at 850°C . under the conditions named as regards length of immersion in the quenching bath. The sixth chart, Fig. K, gives the distribution of hardness (Brinell method, 1 mm., 30 kg.) on a longitudinal section of a bar (APQ) after quenching in oil

at 850° C. The figures given in *italics* represent the Brinell hardness numbers at as nearly as possible the same positions, retaken after tempering for thirty minutes at 300° C. in an electrically heated furnace, followed by quenching in water. It will be seen that in the majority of positions, where the initial hardness in the material as quenched is high, there has been a decided fall in hardness as the result of tempering at 300° C. On the other hand, there are a number of positions in which the initial hardness is relatively low, and this

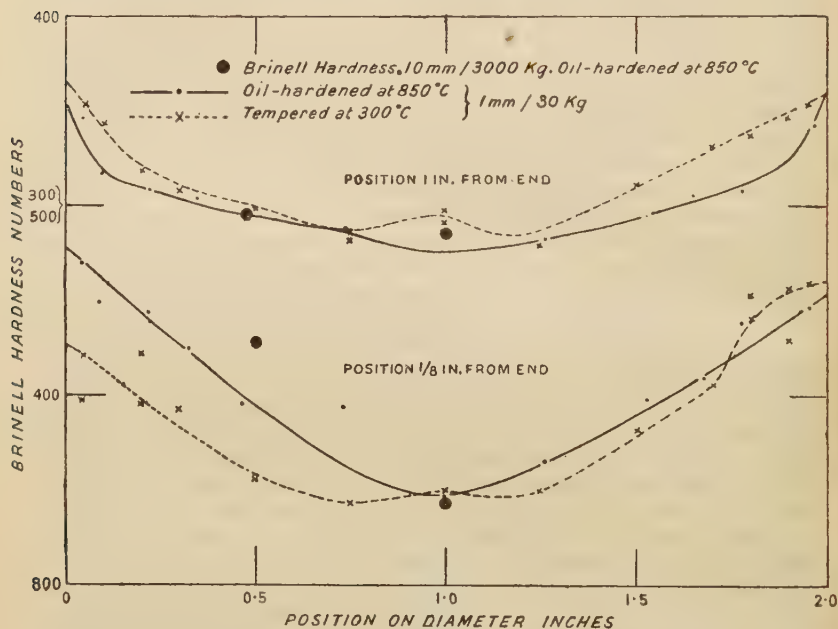


FIG. M.—AEG material, Bar 4A1. Brinell hardness tests on a diameter of a bar 2 in. in diameter \times 5 in. long, quenched in the manner used for plain carbon steels.

hardness rises after tempering. Figs. M, N, and O show the results of Brinell hardness tests made on diameters of transverse sections from another series of bars of the same material, 2 in. in diameter and 5 in. in length, quenched from 850° C. with a short immersion in the quenching bath. The full lines show the hardness as quenched, while the dotted lines give the results of hardness tests after the bars had been tempered at 300° C. It will be seen that in several instances there is a very marked rise in hardness as the result of tempering; for instance, the centre of bar AEG4B1 (Fig. N) shows a rise from 285 to 320. These results, although they do not show an increase in hardness quite as great as that shown in some cases in the original paper, are yet

sufficient to establish the fact that, under certain conditions of hardening and tempering, tempering at 300°C . does produce a very marked rise in hardness. The possibility that such an action could occur does not appear to have been known or recognised previously, and to that extent the results may claim to be regarded as a definite advance in our knowledge of the behaviour of nickel steel on heat

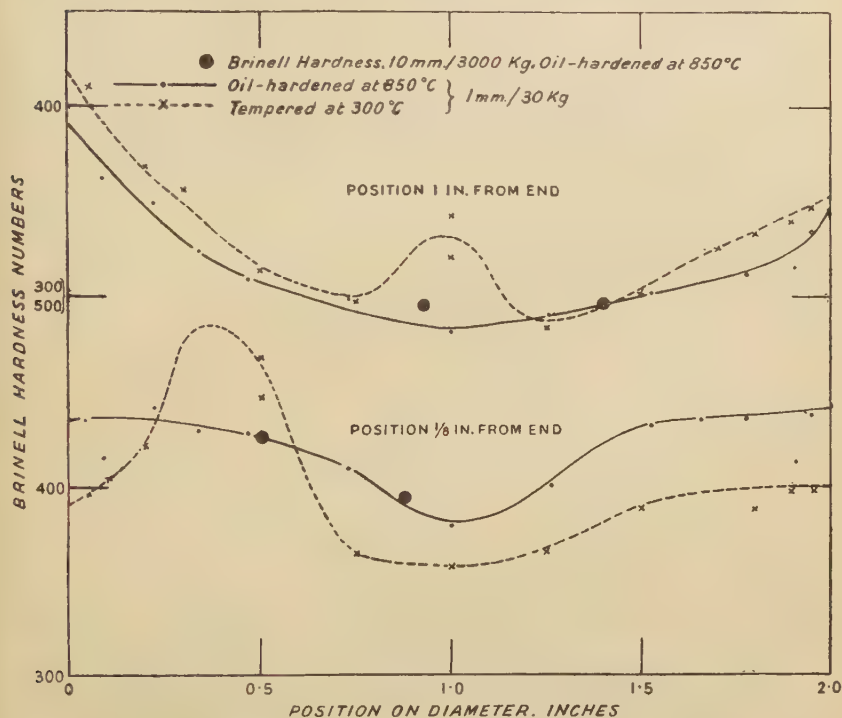


FIG. N.—AEG material, Bar 4B1. Brinell hardness tests on a diameter of a bar 2 in. in diameter \times 5 in. long, quenched in the manner used for plain carbon steels.

treatment. At the same time, however, the results here presented, which cover a very large number of hardness determinations, and a very thorough exploration of a number of quenched and tempered specimens, indicate that the phenomenon of hardening on tempering at 300°C . only occurs occasionally and under conditions not yet fully understood in the heat treatment of this steel, although it was encountered in the particular tests described in the original paper. In view of the great variability of hardness both in the "as quenched" and "as tempered" conditions which has been observed in

this particular type of steel, it is obviously very difficult to represent in any rational manner the change of hardness produced by tempering by such a graph as the authors attempted to put forward in their Figs. 1 to 4.

In the light of the results just described, and particularly in view of the unavoidable variability of hardness found in the check experiments, it appears that the graphs as drawn in the paper as originally

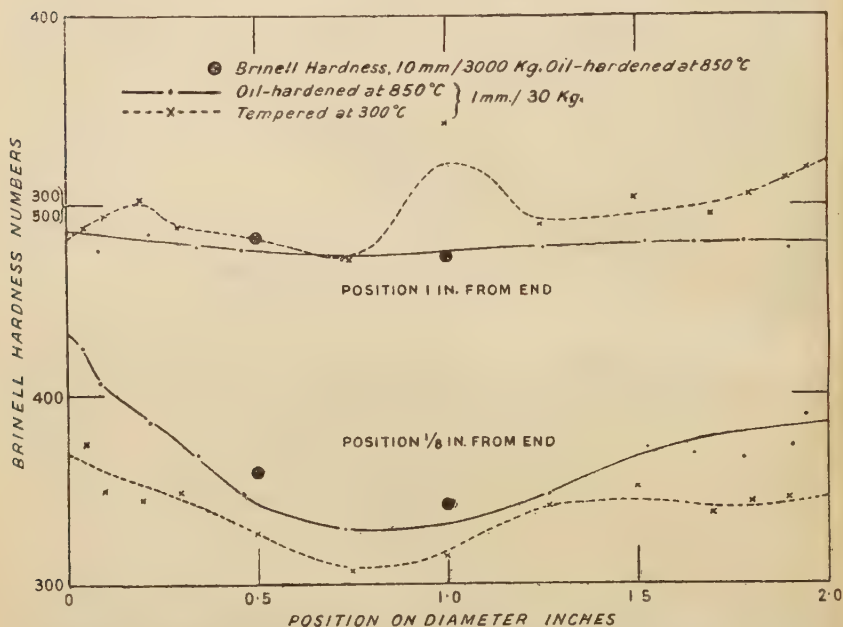


FIG. O.—AEG material, Bar 4C1. Brinell hardness tests on a diameter of a bar 2 in. in diameter \times 5 in. long, quenched in the manner used for plain carbon steels.

presented (Figs. 1 to 4) do not represent satisfactorily the average behaviour of the steel. While they represent actual experimental fact, which criticism has, as will now appear, entirely failed to shake in any way, they ignore the variability of the results which are obtained for the hardness, and therefore for the strength of the material both in the "as quenched" and "tempered at 300° C." conditions. The graphs as they stand represent what may be somewhat extreme examples of the test results which can be obtained from materials properly quenched and tempered at 300° C., but, in view of the results subsequently obtained by further investigation, they do not represent mean results which would be obtained over an average of a considerable

number of cases. For that reason it would be preferable to modify these graphs and to leave the points found for the material as quenched and after tempering at 300° C. unconnected by lines. Actually, the points indicating the results for the material as quenched and after tempering at 300° C. might be placed anywhere over a very wide range, as the range of hardness figures given in the diagrams attached to this communication proves. To connect points of this kind by a direct line might lead to misinterpretation, and a note has therefore been added below the diagrams of the properties determined on the 2-in. and 4-in. bars directing attention to the further investigation described here. Nothing in the above account, however, justifies the suggestion, made in the original criticism, that the experimental facts were not correctly determined.

VISITS AND EXCURSIONS AT THE GLASGOW MEETING.

THE Autumn Meeting of the Iron and Steel Institute was held at Glasgow by the kind invitation of the President and Council of the West of Scotland Iron and Steel Institute. The Meeting was held on September 20, 21, and 22, 1927. An influential General Reception Committee was formed for the purpose of welcoming the visitors, with an Executive Committee for making the necessary arrangements for their entertainment.

The General Reception Committee was composed of the following noblemen and gentlemen: The Right Hon. The Lord Provost of Glasgow; The Right Hon. Lord Belhaven and Stenton; The Right Hon. The Earl of Home; The Right Hon. Lord Blythswood; The Right Hon. Lord Invernairn of Strathnairn; The Right Hon. Lord Maclay, Bt.; The Right Hon. Lord Weir; Sir Steven Bilsland, Bt.; Sir Iain Colquhoun, Bt.; Sir Henry Hamilton Houldsworth, Bt.; Sir D. M. Stevenson, Bt.; Sir John Samuel, K.B.E.; Sir Thos. Bell, K.B.E.; Sir John Hunter, K.B.E.; Sir Adam Nimmo, K.B.E.; Sir Robert Bruce, K.T., LL.D., D.L., J.P.; Sir Archd. M'Innes Shaw, C.B.; Sir Henry Meehan; Sir Matthew W. Montgomery; Sir Alex. M. Kennedy; Principal Sir Donald MacAlister, Bt.; Commander A. B. A. Macdonald; Major-General H. F. Thuellier, C.B.; Professor J. H. Andrew, D.Sc.; Professor Daniel Burns, M.Inst.M.E.; Professor Robt. M. Caven, D.Sc., F.I.C.; Professor Robt. W. Dron, F.R.S.E.; Professor Thos. Gray, D.Sc., Ph.D., F.I.C.; Professor G. G. Henderson, D.Sc., LL.D., F.R.S.; Professor Geo. W. O. Howe, D.Sc.; Professor A. L. Mellanby, D.Sc.; Professor W. R. Scott, M.A., D.Phil., Litt.D., LL.D.; Professor Stanley Parker Smith, D.Sc., M.I.E.E.; Professor F. J. Wilson, D.Sc., Ph.D., F.I.C.; Herbert F. Stockdale, LL.D., F.R.S.E.; Emeritus Professor Magnus Maclean, M.A., D.Sc., LL.D., F.R.S.E., M.I.E.E.; John Craig, C.B.E., President, West of Scotland Iron and Steel Institute; Captain V. B. Stewart, C.B.E.; J. Foster

King, C.B.E. ; Harold E. Yarrow, C.B.E. ; Bailie Mrs. Bell, Chief Magistrate, Corporation of The City of Glasgow ; Bailie D. C. Fletcher ; Bailie James Stewart ; Bailie A. Munro, J.P. ; Councillor John Taylor ; Councillor James Walker ; Allan Adam ; John Alston ; A. Anderson ; C. G. Atha ; Sam. Beale ; Herbert Beard ; John Bell ; Thomas Bell ; Wm. D. Besant ; H. W. Bewsher ; J. Bird ; T. C. F. Brochie ; Matthew Brown ; J. D. Brunton ; J. Bryden ; J. J. Cameron ; W. H. Cathcart ; Thos. Cameron, F.C.I.S. ; John Colville ; Wm. Conochie ; John Cranston, D.Sc., A.I.C. ; R. Crichton ; J. R. Cunningham ; J. S. Cunningham ; Wm. Cunningham ; John Dallas, D.L. ; Wm. Downs ; Andrew Eadie ; Wallace Fairweather ; Dan. Fife ; S. E. Flack ; James T. Forgie ; Wm. Fraser ; Norman O. Fulton ; D. J. Garrett ; Lt.-Col. T. K. Gardner ; E. T. Goslin ; Walter G. Gray ; Henry H. A. Greer ; Robt. Hamilton ; Geo. Henshilwood, C.E. ; W. Scott Herriott ; W. A. Hogarth, M.B.E. ; T. A. Irvine ; Jos. Jefferson ; Chas. Ker ; Geo. L. Kerr ; J. Kerr ; John King ; S. B. Langlands, J.P. ; E. H. Lewis, M.A. ; R. B. Maccall, J.P. ; Douglas A. MacCallum, F.I.C., F.C.S. ; A. M'Cance, D.Sc. ; A. K. M'Cosh ; A. C. Macdiarmid ; J. M'Gregor ; K. D. Mackenzie ; T. B. Mackenzie, M.I.Mech.E. ; L. Mackinnon ; James Macleod, F.I.C. ; John W. M'Luskey, M.I.Mech.E. ; Hugh Martin ; Sam. Mavor ; H. Metcalfe ; G. A. Mitchell ; Jas. Mitchell ; Robt. B. Mitchell ; James Montgomerie, D.Sc., M.I.N.A. ; R. D. Moore, B.Sc. ; R. T. Moore, Governor, Royal Technical College ; James Morton, President, Glasgow Chamber of Commerce ; Hugh Neilson ; Geo. Ness, M.I.Mech.E. ; F. P. Nowery ; E. H. Parker ; Geo. Pate ; Septimus A. Pitt ; R. A. Raphael ; James Richardson, B.Sc. ; Louis Ripley ; P. M. Ritchie ; Robt. Robertson, B.Sc., M.Inst.C.E. ; John Archd. Roxburgh, D.L., LL.D. ; Lennox M. Sellar, J.P. ; Provost Smith ; J. Smith, B.Sc. ; J. Balfour Sneddon ; Col. Alan Stein, M.C. ; James Strain ; A. Tarrant ; Joseph Taylor, M.I.E.E. ; J. W. Taylor, LL.B. ; James Tennent ; W. G. Turnbull ; R. M. Wilson ; R. S. Wilson ; W. L. Winning.

The Executive Committee was constituted as follows : Mr. John Craig, C.B.E., President of the West of Scotland Iron and Steel Institute, Chairman ; Mr. W. G. Turnbull ; Mr. Louis Ripley ; Mr. R. Crichton ; Mr. R. Hamilton ; Mr. J. M'Gregor ;

Mr. F. P. Nowery ; Mr. J. R. Cunningham ; Mr. G. Ness ; Mr. T. B. Mackenzie, M.I.Mech.E. ; Mr. John Colville ; Mr. E. H. Lewis, M.A. ; and Mr. Douglas A. MacCallum, F.I.C., F.C.S., who undertook the duties of Hon. Secretary of the Meeting.

The thanks of the Council and Members are due to these gentlemen, and especially to Mr. MacCallum, for the care they devoted to the work of organisation preceding the meeting. Acknowledgments are also particularly due to Mr. Louis Ripley, who took charge of the arrangements for the conveyance of members on their excursions and to and from the place of meeting ; to Mr. F. P. Nowery, who specially assisted in the arrangements for the excursions to outlying districts ; to Mr. G. Ness, who was responsible for the arrangements in connection with the luncheon, dinner, and supper dance, provided by the hospitality of the West of Scotland Iron and Steel Institute ; and to Mr. T. B. Mackenzie, for having prepared the admirable descriptions of all the works visited, which, for the convenience of the members, were issued to them in handy form as part of the programme, under the title "The Iron and Steel Industries of the West of Scotland."

A Ladies' Reception Committee was also formed, the Executive of which consisted of the Honorary Convener, Mrs. David Mason, wife of the Lord Provost of Glasgow ; Mrs. R. Crichton, Convener ; Mrs. J. Colville ; Miss Craig ; Miss Hamilton ; Mrs. E. H. Lewis ; Mrs. D. A. MacCallum ; Mrs. J. M'Gregor ; Mrs. G. Ness ; Mrs. F. P. Nowery ; and Mrs. L. Ripley. Under the direction of this Committee a special programme was arranged for the ladies who accompanied the members, and nothing was left undone that could contribute to their comfort and enjoyment of the meeting.

The Secretaries' Office was situated in the Royal Technical College, George Street, Glasgow, and by kind permission of the Governor and Directors of the College, the General Meetings were held in the Societies' Room of the same building. The proceedings opened at 10 A.M. on Tuesday, September 20, and the Lord Provost of the City (Mr. David Mason), Mr. John Craig, C.B.E., President of the West of Scotland Iron and Steel Institute,

and Mr. James Morton, President of the Glasgow Chamber of Commerce, attended and welcomed the President (Mr. Frank W. Harbord, C.B.E.), the Council and Members to the City of Glasgow. The remainder of the morning and also the mornings of the 21st and 22nd were devoted, as usual, to the reading and discussion of papers, and the official account of these proceedings will be found elsewhere in this volume.

On each afternoon of the three days of the meeting, the party, under the guidance of Mr. L. Ripley, divided into several groups, which were separately conveyed to the works of the following companies: On Tuesday afternoon, (1) Messrs. Babcock and Wilcox, Ltd., Renfrew; (2) Messrs. Frederick Braby & Co., Ltd., Glasgow; (3) Messrs. David Colville & Sons, Ltd., Cambuslang; (4) Messrs. The Steel Company of Scotland, Ltd., Glasgow. On Wednesday afternoon they visited: (5) Messrs. William Beardmore & Co., Ltd., Mossend; (6) Messrs. The Glasgow Iron and Steel Co., Ltd., Wishaw; (7) Messrs. Smith and MacLean, Ltd., Gartcosh; (8) Messrs. Stewarts and Lloyds, Ltd., Mossend; (9) Messrs. Mavor and Coulson, Ltd., Glasgow. On Thursday afternoon the members visited: (10) Messrs. William Bain & Co., Ltd., Langloan; (11) Messrs. The Scottish Iron and Steel Co., Ltd., Coatbridge; (12) Messrs. The Scottish Tube Co., Ltd., Coatbridge; (13) Messrs. R. B. Tennent, Ltd., Whifflet. All the works of these companies were thrown open to the members without reserve, and at the end of the inspection the visitors were hospitably entertained to light refreshments by their respective hosts.

On the Tuesday morning and afternoon, the ladies, under the guidance of the Ladies' Executive Committee, were taken for drives about the city and to places of interest outside. Wednesday was spent by them in making excursions to places some distance from the city; one party travelled to Edinburgh by train and visited various places of interest in that city, and a second party spent the day in making an excursion to Callander. On Thursday afternoon the ladies were taken in special cars to visit the works of Messrs. Macfarlane, Lang & Co., Ltd., biscuit manufacturers, and to those of Messrs. James Templeton & Co., carpet manufacturers.

At the close of the session on Tuesday morning, the 20th, the members and ladies accompanying them proceeded to the Central Hotel, where the whole party was entertained to luncheon by the Reception Committee, Mr. John Craig, C.B.E., Chairman, presiding. After luncheon, Mr. Craig welcomed the members again on behalf of the Reception Committee and proposed the health of Mr. Frank W. Harbord, C.B.E., President, who replied in a few words, thanking Mr. Craig and his Committee for the generous and hospitable reception accorded the visitors and their friends.

On Tuesday evening, the 20th, a Reception by the Right Hon. Lord Provost and Corporation of the City of Glasgow was held in the City Chambers. After receiving the members and their ladies, the Lord Provost, the Magistrates, and all their guests assembled in the Banqueting Hall, where the Lord Provost, in an eloquent speech, welcomed the visitors as the guests of the Corporation of the City of Glasgow, to which Mr. Craig and Mr. Harbord suitably replied. These proceedings were followed by a Dance in the Banqueting Hall, the music being rendered by Mr. John Millar's Orchestra. In the Council Hall the Glasgow Select Choir conducted by Mr. Thorpe Davie, and with Mr. Wallace Andrew at the piano, rendered an excellent programme of vocal music.

On Wednesday, September 21, after the close of the business session on that morning, all the members were entertained to luncheon at the Central Hotel by the President (Mr. James Morton) and directors of the Glasgow Chamber of Commerce, and a cordial welcome was extended to the guests by Mr. Morton and his colleagues, to which Mr. Frank W. Harbord, the President, replied.

On Wednesday evening all the members and their ladies were entertained to Dinner at the Central Hotel by the General Reception Committee, Mr. Frank W. Harbord, the President, being invited to occupy the Chair. After Dinner, and following the usual Loyal Toasts, the Toast of "The Lord Provost, Magistrates and City of Glasgow" was proposed by Mr. Benjamin

Talbot, President-Elect, to which the Right Hon. the Lord Provost (Mr. David Mason) replied. Mr. James Morton, President of the Glasgow Chamber of Commerce, then proposed the Toast of "The Iron and Steel Institute," to which Mr. Frank W. Harbord, the President, responded. Finally, Sir William Larke, Director of the National Federation of Iron and Steel Manufacturers, proposed the Toast of "The Scottish Industries," coupled with the name of Mr. John Craig as President of the West of Scotland Iron and Steel Institute, and to this Toast Mr. John Craig spoke in reply.

On Thursday, September 22, the members and their ladies were again entertained to luncheon by Mr. John Craig, President of the West of Scotland Iron and Steel Institute, and the Reception Committee at the Central Hotel, Mr. Craig occupying the Chair. Mr. Craig took occasion to express his satisfaction with the manner in which the programme had been carried out in spite of the unfavourable weather conditions, and to give utterance to the great pleasure which it had given to himself and his colleagues to find that the meeting was so well attended and that all the arrangements had been carried out in such a highly successful manner.

On the same day, after lunch, the parties visiting works at Coatbridge were received by the Provost and Town Council in the Town Hall of Coatbridge, which had been beautifully decorated for the occasion. The Provost and Councillors were present to receive the visitors, and extended to them a most hearty welcome. On the conclusion of the complimentary speeches by the Provost and Mr. Craig, the whole party divided into groups to visit the various works on the programme for that afternoon, returning afterwards to the Town Hall to partake of tea and light refreshments.

On Thursday evening, by invitation of the Reception Committee, a Supper Dance was held in the Central Hotel. All the members and their ladies, with a number of their friends from the neighbourhood, attended, and a very enjoyable evening was spent.

On Friday, the 23rd, the whole day was devoted to an excursion on the Firth of Clyde on the T.S.S. *King George V*. The whole of the arrangements for the excursion were made by the Reception Committee. The majority of the members and their ladies embarked on the steamer at Broomielaw, while the remainder proceeded by train to Gourock and there joined the steamer. Leaving Gourock, the steamer proceeded across the Firth through the Kyles of Bute towards Ardrishaig, and returned past Largs and Wemyss Bay to Gourock. An excellent luncheon was provided on board, and a group of pipers of a Highland regiment was in attendance. The weather proved magnificent, and after a delightful day the whole party returned to Glasgow, whence they dispersed to their several destinations.

During the days of the meeting the Committees of Management of the Conservative Club, the Constitutional Club, the Liberal Club, the Automobile Club, the City Business Club, and the Royal Exchange were good enough to accord to the visiting members the use of their premises, a privilege which was highly appreciated.

OBITUARY.

JAMES M. CAMP died at Pittsburgh on October 24, 1927, following a short illness. He was born in Pittsburgh in 1859, and graduated as a Civil Engineer from what is now the University of Pittsburgh. His first association with the steel industry was in 1882, when he became assistant chief chemist of the Pittsburgh Steel Casting Co., Pittsburgh. In 1889 he was appointed chief chemist at the plant of the Allegheny Bessemer Steel Co., which later became the Duquesne Works of the Carnegie Steel Co. He remained at that plant in charge of the chemical and physical testing department until 1911, during which time he served for one year as assistant superintendent of blast-furnaces under James Gayley. In 1907 he was appointed Chairman of the Chemists Committee of the United States Steel Corporation, and held that position until his death. As head of the Committee he had charge of the compilation of all the books published on the results of the activities of the Committee. Since 1911 he had been director of the educational activities of the Carnegie Steel Co., which included a school for salesmen and works schools to provide technical training for workmen, at the Homestead, Duquesne, and Edgar Thomson works. He twice presented papers before the American Iron and Steel Institute—in 1912, "Technical Training for Salesmen," and in 1921, "The Relation of the Iron and Steel Industries to the Chemical Industries." He also wrote, in collaboration with C. B. Francis, "The Making, Shaping, and Treating of Steel," a text-book in common use in technical schools and colleges in America, and generally recognised as authoritative in the field of iron and steel manufacture. He was a member of the American Iron and Steel Institute, the Engineers Society of Western Pennsylvania, the American Society for Steel Treating, and the American Chemical Society. At the time of his death he was director of the Bureau of Technical Instruction of the Carnegie Steel Co. He was elected a member of the Iron and Steel Institute in 1901.

BARNETT COHEN died recently at the age of sixty-two. He was vice-chairman of George Cohen, Son & Co., Ltd., Iron and Metal Merchants of London. His business activities included that of chairman of the Shipbreaking Co., Ltd., Briton Ferry, and other associated companies. He was elected a member of the Iron and Steel Institute in 1916.

Sir JOHN C. DAVIES, C.B.E., J.P., Vice-President of Baldwins Ltd., died on August 29, 1927, at his residence, "Stelvio," Newport, aged sixty-three years. A native of Gowerston, near Swansea, he entered the industry at quite an early age, and his exceptional ability enabled him

to rise from the position of a furnaceman to one of the most responsible in the trade. Under his guidance the resources of Baldwins Ltd. were utilised to their full for the manufacture of shell steel during the war. He was one of the founders of the Swansea National Shell Factory at Landore, and throughout acted as Chairman of the Board of Management. He was also a member of the Executive Committee of the Ministry of Munitions controlling the shell factories in the various areas, and represented the Ministry in the allocation of steel supplies in South Wales. His services during the war gained him both the C.B.E. and the Cross of the French Legion of Honour. He was knighted in 1923. In addition to his vast business interests he for many years took an active part in local government in the Swansea district. He was Vice-Chairman of the South Wales Siemens Steel Association, besides being a member of the Executive Committee of the Welsh Plate and Sheet Manufacturers' Association and of the National Federation of Iron and Steel Manufacturers. He was elected a member of the Iron and Steel Institute in 1899.

WILLIAM HENRY DYSON died on November 12, 1927, at the age of sixty-nine. He had a lifelong association with the coal trade of Hull, and succeeded his father many years ago as head of the firm of W. Dyson & Son, Prince's Dock, Hull. He retired from the business about four or five years ago owing to ill-health. He was elected a member of the Iron and Steel Institute in 1907.

EDWIN L. FORD died on July 4, 1927, aged seventy-one. He was born at Albany, New York, graduated from Yale University, and entered the employ of the Albany and Rensselaer Iron and Steel Co., Troy, New York, going into the Bessemer department. Following this he became associated with the Cambria Iron Co., Johnstown, Pa., and later with the Springfield Iron Co., Springfield, Illinois. In 1882 the Youngstown Steel Co. was formed with Mr. Ford as superintendent. In 1907 he was elected President of the Youngstown Co. When the Brier Hill Steel Co. was formed in 1912 the properties of the Youngstown Co. were absorbed, and he became director of the Brier Hill Co. Then, when the Youngstown Sheet and Tube Co. took over the Brier Hill Co., he was selected for the Board of Directors. Three years ago he built a mechanical puddling plant at Warren, Ohio. He was elected a member of the Iron and Steel Institute in 1892.

ROBERT FORSYTH died at his residence in Chicago on September 11, 1927, following a short illness. He was born at Troy, New York, in 1849, and received his training at the Rensselaer Polytechnic Institute, where he graduated in 1869. He entered the steel industry as a student and draughtsman at the Bessemer Works, Troy, under the tutelage of Alexander L. Holley, and in 1872 was appointed superintendent of the Bessemer department of the North Chicago Rolling-Mill plant. In 1884

he became superintendent of the Spang Steel and Iron Co., Pittsburgh, and in the following year he became manager of the Union Steel Co., Chicago. In 1889 he was made chief engineer and second vice-president of the Illinois Steel Co., holding that position until 1896, when he began practice as a consulting metallurgical engineer in Chicago. He was a member of the American Iron and Steel Institute, the American Society of Civil Engineers, the American Society of Mechanical Engineers, the American Institute of Mining and Metallurgical Engineers, and the Western Society of Engineers. He was elected a member of the Iron and Steel Institute in 1879.

ELBERT H. GARY, Chairman and Chief Executive Officer of the United States Steel Corporation, died in New York on August 15, 1927, at the age of eighty-one. He was born on his father's farm at Wheaton, Illinois, and received his early education in the common schools of Wheaton. Later he attended the Wheaton College and the University of Chicago, from which he received the degree of LL.B. in 1867. In that year he was admitted to the Illinois Bar, and in 1882 to the Bar of the Supreme Court of the United States. In 1871 he became a partner in the law firm of Van Armen and Vallette, in which his uncle was a partner. The disastrous fire which destroyed part of Chicago in 1871 also broke up the law firm, and as soon as possible he started practice on his own. In 1882 he was elected County Judge of Du Page County, and served in that capacity for two terms of four years each, but declined re-election for a third term. He also served as President of the Chicago Bar Association in 1891-1892. His first introduction to the steel industry was through the medium of John W. Gates, who sought his advice in merging five wire companies. The capital was 4,000,000 dollars, and the company was known as the Consolidated Steel and Wire Company. The purchase of stock in the Illinois Steel Co. resulted in his being chosen a director, a post he held from 1895 to 1898. In 1898 he was associated with John W. Gates and J. P. Morgan in a proposal to form a consolidation of the wire companies of the United States with a capital of 80,000,000 dollars. The original plans fell through, but he later succeeded in forming the American Steel and Wire Co., of Illinois, with a capital of 24,000,000 dollars. In the same year was formed, largely through his efforts, the Federal Steel Co., composed of the Illinois Steel Co.; the Lorain Steel Co., and the Minnesota Iron Co. As chairman of the Federal Steel Co. he moved from Chicago to New York. Three years later he organised the formation of the United States Steel Corporation, of which he has ever since been the directing force. His conduct of the industry has been marked by a determined opposition to trade unionism, and an equally vigorous promotion of welfare work among the employees. One of the reforms for which he was responsible was the introduction of an eight-hour day throughout the steel industry. In his relations with other industrialists he favoured, wherever possible, co-operation rather than competition.

From the formation of the United States Steel Corporation he assiduously cultivated friendly relations with foreign industrialists, and took every opportunity of meeting them when on visits to Europe. The formation of the American Iron and Steel Institute in 1908 was always regarded by him as a signal accomplishment. He has been its only president, and its original membership of 106 has grown under his guidance to over 2000. He was elected an Hon. Vice-President of the Iron and Steel Institute in 1922.

ALEXANDER G. M. JACK died in Sheffield on August 2, 1927. At the age of twelve he entered the engineering department of Woolwich Arsenal as an engineer's apprentice, and served seven years. At the age of twenty-two he joined the United States Navy as an engineer, and two years later he erected and set in operation the Nai-Kuang Sze Arsenal, near Tientsin, China, where he remained six years. His long association with Sheffield began when he joined the firm of Hadfields Ltd., in 1888. He served with the firm for thirty-three years, being in turn works manager, general manager, director, managing director, and finally deputy chairman, from which position he retired in 1921. Up to the time of his death, however, his services were always at the disposal of the firm, which he helped in no small measure to develop, in a consulting capacity. He was a member of the Institution of Civil Engineers, and was elected a member of the Iron and Steel Institute in 1890.

JAMES KERR, chairman of the Etna Iron and Steel Co., died at the age of eighty-three. He was connected with the early developments of the iron trade in Coatbridge. He went to the Motherwell district in 1889, where, along with the late Mr. J. Wotherspoon, he purchased the Brandon Iron and Steel Works, Craigneuk, which he renamed. In 1913 he formed the present company. He was elected a member of the Iron and Steel Institute in 1894.

JAMES PATCHETT died at his residence, "Haybridge Hall," Hadley, near Wellington, on July 30, 1927. He was chairman and managing director of the Shropshire Iron Co., Ltd., chairman of the Hadley Trench and Wrockwardine Wood Lighting Co., Ltd., director of the Union Steel Corporation of South Africa, and of other companies. He was a large employer of labour in the manufacture of iron, steel, copper, and bronze, and was a member of the Birmingham Iron Exchange, the Midland Iron and Steel Wages Board, the South Staffordshire Iron Masters' Association, and the Iron and Steel Wire Manufacturers' Association. He was elected a member of the Iron and Steel Institute in 1882.

REGINALD PEASE died on July 12, 1927, at his residence, "Sledwick," Barnard Castle, in his sixty-second year. He was the son of the late Henry Pease of Darlington, who from 1857 to 1865 was Member of

Parliament for the South Division of Durham. He was a joint managing director of the Darlington Forge Co., whose board he joined forty years ago, and a director of the Bearpark Coal and Coke Co., Middlesbrough, and the Carnforth Hematite Iron Co., Ltd. He was elected a member of the Iron and Steel Institute in 1896.

CHARLES FREDERIC RAND died on June 21, 1927, at his home in West Orange, N.J., at the age of seventy. He was a member of the family to which the mining industry owes the Rand drill and air compressor, but his own professional career began in railway construction. His association with the mining industry commenced in 1886, and for the next twenty years his interests lay mainly in the Lake Superior region, where he was the representative of the Rockefeller interests in many important enterprises. He was identified later with the construction of railways and the opening up and operation of mines in Cuba, where he found his major life work. His attention was attracted to the great laterite deposits on the north coast of Cuba. He recognised their value, and in the face of much discouragement found the means of bringing them into production. In the years 1906 to 1909 he developed and equipped the great Mayari properties. From 1901 to 1916 he was in charge of the mining interests of the Pennsylvania Steel Co., and from 1910 to 1917 he was President of the Buena Vista Iron Mining Co. He took a prominent part in the affairs of the American Institute of Mining and Metallurgical Engineers. He was one of the organisers of the United Engineering Society, the Engineering Foundation, the John Fritz Medal Board of Award, and the Mining Medal Board. In 1913 King Alfonso XIII. decorated him with the Grand Cross of Commander of the Order of Isabella la Católica. He was decorated in 1922 with the Croix de Chevalier de la Légion d'Honneur for distinguished services during the World War. He was elected in 1921 an Hon. Member of the Iron and Steel Institute; this honour was bestowed upon him when in England as Hon. Secretary of the John Fritz Medal Board of Award, which bestowed the John Fritz Medal for achievement in applied science on Sir Robert Hadfield, and, later, in Paris, bestowed the medal for 1922 upon Mr. Eugene Schneider, head of the famous Creusot Works.

He was a Past-President of the American Institute of Mining and Metallurgical Engineers, and was a member of the American Iron and Steel Institute, National Research Council, and American Society for Testing Materials. He was elected a member of the Iron and Steel Institute in 1907.

EDWARD STEER, Hon. Vice-President, died at his residence, "The Woodlands," Malpas, Newport, Monmouthshire, on October 29, 1927, at the age of seventy-six. He was born in London in 1851, and was the second son of the late Charles Steer and Martha Nettlefold, a first-cousin of the late Joseph Chamberlain. He was educated at Brighton, and at the age of seventeen he joined his uncle, Joseph Nettlefold,

in the firm of Nettlefold and Chamberlain. When Mr. Joseph Chamberlain retired the firm became known as Nettlefolds, Ltd., and under the supervision of Mr. Steer the Rogerstone Steel and Wire Works were laid out in 1885. In 1886 he went to reside at Malpas, and was appointed managing director of the Rogerstone Steelworks. When Nettlefolds, Ltd., were amalgamated with Guest, Keen & Co., he joined the Board of Directors, of which he became chairman in 1920. He continued to serve in that capacity until last May, when, through ill-health, he resigned, and was succeeded by Lord Buckland of Bwlch. He was also chairman of the Meiros Colliery Co., and was associated with T. Spittle, Ltd., Pipe Founders and Engineers, Newport; Partridge Jones and John Payton, Ltd., Colliery Proprietors and Steel and Tinsplate Manufacturers; John Lysaght, Ltd.; and the Cordes Dos Nail Works, Newport. For a number of years he was director of the Alexandra Docks and Railway Co., Newport, and only severed his connection when the company became absorbed by the Great Western Railway Co.

He was a recognised authority on the iron and steel trade, and his whole life was spent in its service. He was for many years a member of the Monmouth County Council. He took little part in public life, but was appointed a Justice of the Peace for Monmouthshire in 1887. In 1909 he served as High Sheriff, and was appointed Deputy-Lieutenant for Monmouthshire in 1917. During the war he was associated with recruiting, charitable, and other movements, and was chairman of the National Shell Factory at Maesglas. He was elected a member of the Iron and Steel Institute in 1873, Member of Council in 1910, and Vice-President in 1917. For his great services to the Institute he was elected an Hon. Vice-President in 1924. In 1920, when the Institute visited Cardiff, he served on the Executive Committee formed to receive the members, and it was in part due to the unsparing pains taken by him that the meeting was such a great success.

ÉMILE TRASENSTER died at Tilff on August 1, 1927. He received his training at the École de Liège, and commenced his business career with the Cockerill Co., with whom he filled important posts in the collieries and steelworks of that concern. In 1908 he was appointed secretary of the Union des Charbonnages, Mines et Usines Métallurgiques de la Province de Liège, and three years later he founded the Mutual Assurance Association for the coal industry. In 1921 he was appointed to the Chair of Metallurgy at Liège University, and in the same year he was appointed "Professeur extraordinaire." In 1925 the Association des Ingénieurs de Liège conferred upon him the Louis Trasenster prize in recognition of his public work. He was a member of the Science Committee of the last-named Society, and was author of numerous publications on subjects relating to metallurgy and the mineral industry. He also served for some time on the editorial staff of the *Revue Universelle des Mines*. He was elected a member of the Iron and Steel Institute in 1921.

SECTION II.

*NOTES ON THE
PROGRESS OF THE HOME AND FOREIGN
IRON AND STEEL INDUSTRIES.*

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The Editor has been assisted in the preparation of these Notes by R. ELSDON,
Librarian of the Institute.

IRON ORES

AND OTHER METALLIFEROUS ORES USED IN THE IRON AND STEEL INDUSTRY.

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I.—GEOGRAPHICAL DISTRIBUTION OF ORES.

(Arranged in alphabetical order under Countries.)

Africa.—O. R. Kuhn, *Africa's Iron Ore—An Unknown Quantity* (Engineering and Mining Journal, 1927, vol. 123, May 14, pp. 803–808). The author describes the iron ore deposits of Africa; they occur principally in Algeria, Tunisia, Morocco, Belgian Congo, French West Africa, British West Africa, Nyasaland, Madagascar, Union of South Africa, and Rhodesia. Bodies of iron ore are reported from Abyssinia, French Congo, Liberia, Egypt, Sudan, Swaziland, and the Portuguese possessions, but little information, as to either quality or quantity, is available. The ore reserves are tabulated as follows, but the author points out that there is but meagre information on which to base figures :

Country.	Controlled by.	Actual Reserve.	Possible Reserve.
Algeria	France	100 million tons	Large
Tunisia	France	100 " "	...
Morocco	Spain	50 " "	Large
Togoland	France	20 " "	...
British West Africa	England	3 " "	2,000 million tons
Madagascar	France	7.5 " "	...
Union of South Africa	England	1,100 " "	2,000 " "
Rhodesia	England	... " "	6,000 " "
Totals		1,380.5 " "	10,000 " "

Over 80 per cent. of the known iron ore reserves of Africa is controlled by England, and the remainder by France and Spain.

P. Geijer, *The Iron Ores of North Africa* (Jernkontorets Annaler, 1927, vol. 111, pp. 111–130). A report on the iron mines and iron ores of Algeria and Morocco, with a bibliography of the subject.

Asia.—*Iron Ores in Asia Minor* (Iron and Coal Trades Review, 1927, vol. 115, July 22, p. 131). Magnetic iron ore, containing about 70 per cent. of iron, occurs in many parts of Asia Minor. In the form of brown hematite containing 30 to 60 per cent. of iron, the ore is present in deposits in Lazistan. In the form of hematite carrying 60 per cent. of iron, in association with manganese, it occurs in the Sanjak of Ismid and elsewhere. Other occurrences of iron ore are also reported. The resources of Anatolia in manganese ore are of considerable value, and the ore is said to be of excellent quality, the deposits at Phiniki yielding some 51 per cent. of manganese. The most important deposits of chrome ore are in the vilayets of Aidin, Brusa, Adana, and Konia.

Canada.—S. J. Cook, *Sixty Years of Progress in Canada's Mineral Industry* (Canadian Mining Journal, 1927, vol. 48, July 1, pp. 524–529). The author reviews the developments in the mineral industry since the Confederation.

China.—C. Y. Hsieh and C. C. Liu, *Geology and Mineral Resources of S.-W. Hupeh* (Bulletin of the Geological Survey of China, Oct. 1927, No. 9, pp. 29–55). The main portion of the report is devoted to a description of the geology of the district. Occurrences of iron ore and coal are briefly noted.

Germany.—K. Hummel, *Various Types of Manganiferous Iron Ore Deposits in Germany* (Zeitschrift für praktische Geologie, 1927, vol. 35, Feb., pp. 17–22; Mar., pp. 38–42). A study of the origin and character of the manganiferous iron ore deposits which occur in different districts in Germany.

Ireland.—H. P. T. Rohleder, *Coal and Iron Ore Occurrences in North Ireland* (Stahl und Eisen, 1927, vol. 47, Apr. 14, pp. 638–639). A note on the extent and character of the coal and iron ore deposits which occur in Ulster.

Scandinavia.—O. R. Kuhn, *Scandinavia's Iron Ore Reserve 4,600,000,000 Tons* (Engineering and Mining Journal, 1927, vol. 124, Aug. 20, pp. 291–294; Aug. 27, pp. 329–332). The occurrences of iron ore in Sweden, Norway, and Finland are noted, and tables are included showing the production, exports, and reserves of each country. Sweden is, of course, by far the largest producer, and Finland has no production of importance as yet. The iron ores of Swedish Lapland form the largest reserve of magnetite ore in Europe, and probably in the world.

United States.—D. E. Woodbridge, *Available Ore Supply is Limited* (Iron Age, 1927, vol. 119, June 9, pp. 1658–1659, 1720). It is pointed out that a large part of the world's reserve of iron is not available owing to transportation costs, expense of mining, and chemical composition.

The future of the United States as a great steel-making nation rests on the Lake region reserves, especially on those of the Mesabi Range. Without increase in rate of mining, commercial Mesabi ore may last forty years.

E. Y. Dougherty, *Magnetite Deposits of Madera County, California, Constitute Important Reserves* (Engineering and Mining Journal, 1927, vol. 123, May 7, pp. 765-770). The geology of the deposits is described. The economic conditions are, however, considered not yet favourable for the commencement of development projects.

J. T. Pardee, *Manganese-Bearing Deposits near Lake Crescent and Humptulips, Washington* (United States Geological Survey, 1927, Bulletin No. 795A). The Crescent Mine, situated a short distance west of Lake Crescent, in the Olympic Mountains of Washington, yields an unusually high grade of manganese ore, which is suitable for steel-making. Several manganiferous lodes of promising appearance have been found in the same area, and some near Humptulips, on the south side of the mountains. These and deposits on Skokomish River and at other places in the Olympic region are distributed around three sides of the mountains through a distance of 110 miles. The characteristic and generally the most abundant manganese mineral in this belt is bementite, a silicate of manganese that is rare elsewhere. Hausmannite, a suboxide of manganese (Mn_3O_4) that is also rather uncommon, occurs in several of the deposits, and is locally abundant in the Crescent mine, where it forms the most valuable constituent of the ore. In addition, more or less of a manganiferous carbonate is present, and bodies composed of fine-grained quartz and iron oxides form a large but separate part of the lodes. The beds at the horizon of the manganiferous deposits are very incompletely explored and are to be regarded as the possible source of large quantities of ore.

Manganese Discovery in Colorado (Mining Journal, 1927, vol. 157, May 21, p. 444). The discovery of a large and rich vein of manganese ore in Central Colorado is announced. The vein is reported to be 14 ft. wide and of a proved length of 3000 ft. and depth of 300 ft.; tests on 50-lb. samples showed 52.86 per cent. manganese.

J. H. Cole, *Manganese Resources of the North-West, and What is Being Done to Use Them* (Engineering and Mining Journal, 1927, vol. 124, July 30, pp. 165-166).

Magnetite Crystallisation.—G. M. Schwartz, *Magnetite Crystals in Sinters. The Sequence of Crystallisation* (Engineering and Mining Journal, 1927, vol. 124, Sept. 17, pp. 453-455). The author describes the crystals of magnetite which are found in the aggregate after iron ores have been sintered, and from his observations puts forward suggestions as to the sequence of crystallisation in the ores themselves.

Value of Manganese Ore.—J. Lilot, *Study of the Value of Manganese Ores* (Revue Universelle des Mines, 1927, vol. 14, May 15, pp. 137-145).

The unit of manganese has not the same value in all ores. The amount of manganese lost in slag and dust during smelting and the amount of coke and flux required for that operation vary from case to case. The author shows how to calculate the actual value of the manganese obtained from a given ore purchasable at a given price per unit, and, as an example, compares the values of two ores from different localities.

II.—PREPARATION OF ORES.

Ore Concentration.—R. Lämmert, *The Development of the Concentration of Calcined Spathic Ores at the Storch and Schöneberg Mines at Gosenbach* (Archiv für das Eisenhüttenwesen, 1927, vol. 1, July, pp. 9–17; Stahl und Eisen, 1927, vol. 48, Aug. 11, pp. 1327–1328). At these mines dressing was originally carried out by hand. In 1896, however, a wet mechanical plant, comprising crushing, sorting, and settling units, was installed. Electro-magnetic preparation was tried in 1914. The ore was separated after careful roasting and crushing, but the residue contained too much iron. In 1926 wet separation was discontinued, and modern Ullrich magnetic drum separation installed. Mean analyses from eight months working showed 49·7 per cent. iron and 9·31 per cent. manganese in the concentrates, and 8·11 per cent. iron and 1·54 per cent. manganese in the residues; the yield of iron is 95·37 per cent., a figure which will not easily be surpassed.

Ore Sintering.—E. J. Tournier, *Sintering Performance and Costs* (Iron Age, 1927, vol. 120, July 14, pp. 72–74). This is the third and concluding instalment of a series of articles on intermittent sintering by the Greenawalt process.

The "Pehrson" Rotary Dryer (Iron and Coal Trades Review, 1927, vol. 115, July 22, p. 137). An illustrated description is given of the general arrangement of the "Pehrson" dryer for the drying of fine material. A dryer of this type has been in operation for some time at the Hofors Steelworks, Sweden, for drying the charcoal used for a sintering plant.

III.—ORE MINING AND HANDLING.

P. Geimer, *Mining and Haulage of Iron Ores in the Mines of Northern Sweden* (Archiv für das Eisenhüttenwesen, 1927, vol. 1, Aug., pp. 103–109). The author describes and illustrates the mining methods and operations in the iron mines of Gellivare and Kirunavara-Luossavara, and the transport and shipping installations at Narvik, Luleå, Rotterdam, and Emden. Conditions of ownership of the mines are also

referred to. The Trafik A.B. Grängesberg-Oxelösund controls these mines, and the State has a large interest in them as well.

A. E. Fritzberg, *Mining Manganese Dioxide. The Trout Mine, at Philipsburg* (Engineering and Mining Journal, 1927, vol. 124, Oct. 22, pp. 645-647). The ore deposits and method of mining are described. Much of the ore is suitable for chemical purposes.

J. R. Linney, *Mining, Refining, and Sintering of Adirondack Magnetites* (Freyn Design, 1926, vol. 1, Oct., pp. 1-4). An account is given of the practice of the Chateaugay Ore and Iron Co., Standish, N.Y. The company operates iron mines in the Adirondack Mountains and a blast-furnace at Standish for the production of low-phosphorus pig iron. The sintering machine is of the Dwight Lloyd horizontal type, and is stated to be the largest machine of this type in use, having a capacity of 50 tons of sinter per hour.

REFRACTORY MATERIALS.

Occurrence, Properties, Manufacture, and Uses of Refractories.—

W. M. Weigel, *Technology and Uses of Silica and Sand* (United States Bureau of Mines, 1927, Bulletin 266). The occurrence, mining, preparation, and uses of quartz, quartzite, sandstone, sand, tripoli, flint and chert, and diatomaceous earth are described. In metallurgy the chief uses are: quartz as a source of silicon in ferro-silicon manufacture, quartzite for silica brick manufacture, sandstone as an acid flux in smelting, and sand for moulding in foundry practice.

E. J. Vachuska and G. A. Bole, *Notes on Cyanite and Diaspor Refractories* (Journal of the American Ceramic Society, 1927, vol. 10, Oct., pp. 761-773). This investigation covers a survey of some cyanite, diaspore, and clay refractories. The work is divided into three sections: (1) diaspore-cyanite study: (2) diaspore-clay and cyanite-clay study: and (3) commercial production and tests. Results of routine tests made with each set of test specimens are given. The addition of 20 per cent. or more of cyanite to diaspore tends to counteract the shrinkage of diaspore during continued use at high temperatures.

W. J. Rees, *Some Notes on the Uses of Indian Sillimanite* (Paper read before the Ceramic Society, May 1927). Very promising results have been obtained with sillimanite bricks in the arches and walls of high-pressure boiler furnaces. The mechanical strength at high temperatures of well-burned sillimanite bricks with 15 to 25 per cent. of fireclay bond is much superior to that of fireclay bricks. The results of tests on a series of briquettes are given.

Notes on Mullite Refractories (American Refractories Institute, Technical Bulletin No. 7; abstract, Blast-Furnace and Steel Plant, 1927, vol. 15, July, pp. 361-362).

A. W. Comber, *Deadburnt Magnesite as a Refractory* (Metal Industry, 1927, vol. 31, Aug. 19, pp. 146, 157). The article describes briefly the properties and uses of deadburnt magnesite, but is mainly concerned with the burning process. The procedure adopted in Austria, Greece, and in India when it was carried out there, is noted. In order that the product may be truly deadburnt, very high temperatures are necessary, but it is a fact of considerable economic importance that the presence of 2 or 3 per cent. of iron lowers the sintering temperature without depreciating the value of the final product as a refractory.

H. Insley, *The Quantitative Microscopic Analysis of Commercial Feldspar* (Journal of the American Ceramic Society, 1927, vol. 10, Sept., pp. 651-669). This investigation was undertaken to develop

microscopic methods for determining quantitatively the mineral constituents in feldspars used in the ceramic and allied industries. After several methods had been tried, a method of counting the grains and using liquids of different indices of refraction for distinguishing the constituents was finally adopted.

S. S. Cole, *The Effect of Size of Grain upon the Properties of Silica Cement* (Journal of the American Ceramic Society, 1927, vol. 10, Aug., pp. 643-650). A thorough study has been made of the effect of size of grain upon the softening point and linear change of silica cements prepared in the laboratory. The ratio of grain-sizes in a cement of constant chemical composition has a distinct effect upon the softening point. The linear change after heating to 110° C. and 1300° C. was not appreciably affected by variation in grain-size. From data obtained by testing a large number of commercial cements it is concluded that, owing to variations in clay content, screen analyses are not definitely related to rate of settle or to softening point. A method for determining "rate of settle" is described.

A. H. Middleton and C. Bride, *Silica Bricks for Steelworks* (Journal of the West of Scotland Iron and Steel Institute, Session 1926-27, vol. 34, Part 5, pp. 64-75). The authors describe the methods of manufacturing silica brick, with a view to showing how the different characteristics of the brick are produced, to what extent they can be controlled, and what differences in behaviour in use may be expected as a result of such variations. The most resistant structure seems to be that developed by producing a medium-grained texture in the grinding process and by giving material sufficient firing in the kilns to produce the strongest possible tridymite growth in the matrix. By this means the porosity is reduced, and, in addition, a hard structure is produced which will resist the abrasive action of the furnace gases.

W. Hugill and W. J. Rees, *A Note on Silica Bricks Made Without Added Bond* (Paper read before the Ceramic Society, Sept. 1927). The authors found that by the ordinary hand-moulding methods, and with suitable grading of the silica rock, silica bricks of fair mechanical strength can be made without using bonding material. A ganister and two quartzites were used for making the bricks, all containing about 97 per cent. silica and all being well washed before using. About half the material was passed through a 100-mesh sieve (much of it being very fine), nearly a quarter through a 10-mesh, and the rest through 80, 30, 20, and 5-mesh sieves. The compressive strengths of the unbonded bricks were about 28, 30, and 39 lb. per sq. in. respectively. Corresponding bricks with 2 per cent. of lime added gave 64, 49, 63 lb. per sq. in. Expansion during firing was much greater in the unbonded bricks than in those bonded with lime. The degree of quartz conversion was greater in the bricks without added bond, but the inversion was almost entirely to cristobalite, whilst in the bricks with lime bond tridymite was formed in fair proportion.

A. T. Green, *The Firing Properties of Refractory Fireclay Products* (Transactions of the Ceramic Society, Session 1926-27, vol. 26, Part 2,

pp. 110-131). The author surveys the fundamental firing characteristics of fireclays in relation to the industrial operation. The constitution of fireclays, the nature of the firing operation, water-smoking, the changes in the porosity, specific gravity, &c., of fireclay products during firing, the oxidation period, the vitrification range, constitutional changes taking place during the vitrification range, and time-factors are discussed.

R. S. Troop and F. Wheeler, *Some Experiments in Drying Clay* (Paper read before the Ceramic Society, Sept. 1927). The calculation of the drying contraction of clay from linear measurements is open to the objection that the method of making the test-piece may materially affect the results obtained. Accidental stretching or compressing of the sample, which are not easily avoided, may appreciably affect the apparent contraction. Distortion of the test-pieces, which is also difficult to prevent, may lead to erratic results. Air-dried bricks of Stourbridge clay showed considerable differences in the linear contractions measured in different directions.

Volume contractions determined by a method devised by S. R. Hind gave very good and reliable results. Some results thus obtained with Stourbridge clay, ball clay, and china clay are shown graphically. The "main contraction" is in all cases uniform and equivalent (or nearly so) to the volume of the water removed by evaporation. This is followed by the "residual contraction," the rate of contraction becoming suddenly very small, but remaining moderately uniform until the "100° C. dry" state. With Stourbridge fireclay, the change took place at a moisture content of 14 to 15.7 per cent., with ball clay at 12 per cent., and with china clay at 28 per cent. In the case of china clay, there was no contraction between 28 per cent. and 11 per cent. of moisture, but actually a slight expansion, as was observed with several different china clays, but no others.

Rate of drying apparently has no marked effect on the contraction. Contraction can be found indirectly by applying Robinson's "plastocene" coating method for measuring the "wet volume," and weighing a similar test-piece before and after drying. This method has the great advantage of elimination of errors caused by the method of making the test-piece.

It was suggested that the use of clay in a much drier state than usual would avoid much loss from distortion, and that the practicability of such procedure is well worth investigating.

G. A. Bole, J. Blizard, W. E. Rice, E. P. Ogden, and R. A. Sherman, *Problems in the Firing of Refractories* (United States Bureau of Mines, 1927, Bulletin 271). This report gives the results of an investigation carried out by the Bureau of Mines which had as its aim: (1) To increase the efficiency of burning conditions in the particular plants where the tests were run; and (2) to obtain data that would be of general value to the refractories industry. Some problems of general interest upon which special data were gathered are as follows: (1) Heat distribution; (2) proper proportions of kilns; (3) manner of setting

ware to obtain best distribution of heat ; (4) open *versus* closed firing ; (5) progress of combustion in kilns ; (6) induced *versus* natural draught ; (7) smoke prevention ; (8) laboratory control of firing practice ; (9) oxidation of sulphur ; and (10) equipment for high-temperature measurements.

M. C. Booze, *Shrinkage of Fireclay Refractories* (Blast-Furnace and Steel Plant, 1927, vol. 15, June, pp. 301-302). A brief note on the causes of the contraction of refractory shapes. The quantity of moisture, fine grinding, burning, &c., are factors determining the magnitude of the change of size.

M. C. Booze, *Studies Refractory Shrinkage* (Iron Trade Review, 1927, vol. 81, Oct. 20, pp. 968-969). The author discusses factors affecting shrinkage of firebrick. Contraction is due largely to the evaporation of mechanical water during drying and to the attraction of single solid particles during initial burning and in use.

R. A. Maloney, *Manufacture of Refractory Shapes* (Blast-Furnace and Steel Plant, 1927, vol. 15, June, pp. 302-303). A brief note on the composition of fireclays, the properties required in them, and the manufacture of fireclay bricks.

F. Lepersonne, *Notes on Refractory Bricks* (Revue Universelle des Mines, 1927, vol. 15, July 15, pp. 76-82 ; Aug. 15, pp. 166-171). The author gives brief notes on the manufacture and properties of bricks of silico-alumina, bauxite, magnesite, chromite, and silica, together with other information, such as specific weights, porosity, fusion points, coefficients of dilatation, heat conductivity, and spalling.

H. S. Orth, *Producer-Gas in Connection with Firing Firebrick* (Journal of the American Ceramic Society, 1927, vol. 10, Sept., pp. 699-703). Features in connection with firing firebrick are discussed. In the firing of tunnel kilns a high temperature at the charging end is essential. Desired features of producer-gas firing are discussed and a producer-gas-fired tunnel kiln installation is described in detail. It is shown that production capacity is dependent on the charging end temperature.

W. Obst, *Most Recent Processes for the Manufacture of Refractory Materials* (Feuerfest, 1927, vol. 3, Aug., pp. 129-130). A brief review of some of the most recently proposed materials for the production of refractory materials.

T. W. Talwalkar and C. W. Parmelee, *Measurement of Plasticity* (Journal of the American Ceramic Society, 1927, vol. 10, Sept., pp. 670-685). The object of this investigation was to devise a rational method and primary standard for measuring plasticity. Various methods suggested in the past were critically examined and found wanting. An apparatus was developed to measure the stress-strain relations of clays in shear, and a few typical clays were examined by this method. A definition was proposed for the unit of plasticity as follows :

$$\text{Index of plasticity} = \frac{\text{Total deformation at fracture in shear}}{\text{Average stress beyond proportional limit}}$$

The effect of addition of sand and powdered graphite, which throws some light on the nature of plastic deformation, was noted.

A. E. MacGee, *Some Thermal Characteristics of Clays* (Journal of the American Ceramic Society, 1927, vol. 10, Aug., pp. 561-568). The literature pertaining to thermal reactions, specific heats, and thermal conductivities of clays is reviewed and discussed, particular attention being given to the heat required to fire various clays. Practically all clays undergo an endothermic reaction between 100° and 650° C., reaching a maximum at about 550° C., which absorbs from about 40 to 130 calories per gram. of air-dried material. An exothermic reaction takes place at about 950° C., which evolves from 10 to 40 calories per gram. The specific heats of clays and shales are about 0.45 over the interval 20° C. to 1100° C.

R. F. Geller, *The Behaviour of Clay Refractories in Service* (Fuels and Furnaces, 1927, vol. 5, Sept., pp. 1189-1192). The author discusses the thermal expansion of clay refractories.

A. J. Dale, *The Testing and Behaviour of Refractory Material under Stress at High Temperatures* (Transactions of the Ceramic Society, Session 1926-27, vol. 26, Part 2, pp. 138-155). The previous work of the author and other investigators is summarised. Typical load-test results provided by silica and firebrick materials differing widely in constitution are presented and discussed, and the industrial interpretations of certain of the findings are suggested. The author has found that silica bricks containing unconverted quartz are liable to disruption under high external load at temperatures above 1250° to 1300° C., unless a specially elastic matrix is present. Silica bricks containing much cristobalite did not fail under even heavy loads below 1700° C. With silica bricks containing much tridymite the subsidence range under small loads (4 lb. per sq. in.) extends over 150° to 180° C., whereas with many silica products it is seldom more than 50° to 80° C. The results obtained lead the author to suggest that the proper application of the modified Mellor and Moore load test will enable a scientific choice to be made of silica bricks for any specific type of industrial service. In connection with fireclay products the results indicate: (1) That a brick with high ferric-oxide content is not necessarily inferior as regards refractoriness at moderate temperatures. (2) A brick of low refractoriness may be efficient enough below 1250° C. but the margin of safety would be very small. (3) High alumina content and moderate porosity favour refractoriness at temperatures up to about 1400° C. (4) The temperature of complete squatting of a brick under load is not a safe guide regarding behaviour of the material at lower temperatures.

A. J. Dale, *The Effects of Temperature on the Mechanical Properties of Silica Products* (Paper read before the Ceramic Society, Oct. 1927). The term "silica product" implies a material containing more than 92 per cent. of silica. Tests were carried out on laboratory-made bricks formed from different raw materials, and also on commercial products.

There was also an investigation of certain clay-bonded silica bricks. The standard rate of heating was to raise the temperature 50°C. per 5 minutes. The results of tests on commercial silica bricks indicate that they fall into two fairly distinct classes. The mechanical properties of bricks of the first class at different temperatures are characteristic of a supporting structure containing cristobalite, with little tridymite, but more or less unconverted quartz. If much unconverted quartz is present in such a structure, the mechanical stability at high temperatures will appear to be to a large extent dependent on the viscous properties of the bond, on the degree of cohesion between bond and silica particles, and on the original quartz grading. In comparison, the mechanical properties of bricks of the second class at different temperatures are consistent with a considerable tridymite content. It may be that a kiln treatment which produces a large amount of tridymite also ensures the relative absence of unconverted quartz, and eliminates the high-temperature weakness shown by bricks of the first class below 1500°C. under the test conditions. Bricks of the second class may suffer disruption in the high-load test between 1540° and 1600°C. , presumably owing to incipient mechanical weakness during the tridymite-cristobalite conversion under the test conditions, or to gradual softening of the bond.

H. R. Goodrich, *Spalling and Loss in Compressive Strength of Firebrick* (Journal of the American Ceramic Society, 1927, vol. 10, Oct., pp. 784-794). A preliminary report of the loss of compressive strength when fireclay bricks are subjected to a series of heat treatments at 1350° and 1250°C. It illustrates some of the variations of heat treatment in the manufacturer's kilns and the differences between the high siliceous type of firebrick and the vitrifying clay type with lower free silica content. It is possible that a satisfactory spalling test may be developed in this direction.

W. C. Hancock and J. G. Cowan, *The Crushing Strength of Unfired Fireclay Bodies* (Paper read before the Ceramic Society, Sept. 1927). The materials used were a mixture of two Stourbridge pot clays, ground to pass a sieve of 30 meshes to the linear inch, and "grog" from hard-fired Stourbridge clay crushed and sieved to give a fine and a coarse grade (the latter between $\frac{1}{8}$ in. and $\frac{1}{16}$ in., and the former between $\frac{1}{16}$ in. and 30 mesh).

The five bodies used for the test-pieces were neat clay, 80 per cent. clay with 20 per cent. fine grog, the same but with coarse grog, 60 per cent. clay with 40 per cent. fine grog, and the same with coarse grog instead of fine. The tensile strengths of these were 156, 171, 137, 108, and 71 lb. per sq. in. respectively, all these numbers being averages of five tests.

Three forms of test-piece were used for the crushing strength: cylinders 1 in. diameter and 2 in. high, rectangular blocks 2 in. by 1 in. by 1 in., and cubic blocks having 2-in. edges. The results are gathered in the following table:

Crushing Strength in Pounds per Square Inch.

Body.	I.	II.	III.	IV.	V.
Cylinders	478	527	442	438	329
Rectangular blocks. Major axis .	724	433	596	474	268
Rectangular blocks. Minor axis .	719	724	...	724	542
Cubes	926	950	841	671	600

In the crushed test-pieces three types of fracture were observed—viz. fracture due to “cone” formation, fracture due to (plane) shearing, and fracture due to a combination of the other two types.

A. H. Stang, *A Portable Apparatus for Transverse Tests of Brick* (United States Bureau of Standards, 1927, Technologic Paper No. 341).

F. A. Wickerham, *The Gas Permeability of Refractory Brick used in Metallurgical Furnaces* (Paper read before the American Iron and Steel Institute, May 1927). The author describes an investigation carried out to determine the gas permeability of bricks used in furnace construction, with a view to providing means to prevent or reduce the loss of heat due to passage of gas through the brick walls. The effect of area of brick, effect of differences in pressure, relative permeability, effect of thickness of the brick, heat-insulating brick, and the effect of mortar at the joints are discussed. The gases available for the tests were coke-oven gas, commercial hydrogen, carbon dioxide, butane, and acetylene. While the gases used were not pure gases, besides containing more or less water vapour by being confined in the gasometer, it is evident from the results that the time for a given amount of gas to pass through a brick bears no relation to the density of the gas. The author also discusses the permeability of brick at elevated temperatures and the prevention of the flow of gases through brick.

A. Wishnevsky, *Thermal Conductivity of Refractories* (Forging, Stamping, Heat Treating, 1927, vol. 13, Aug., p. 327; Blast-Furnace and Steel Plant, 1927, vol. 15, June, p. 309). The thermal conductivities of a number of refractory materials over various ranges of temperature are recorded graphically.

R. Meisterhans, *Graphic Method for Determining the Coefficients of Heat Transmission through the Walls of Structures* (Chaleur et Industrie, 1927, vol. 8, May, pp. 269–274).

G. S. Schaller, *A Study of Cupola Lining Refractories* (Paper read before the American Foundrymen's Association, June 1927). The author discusses the failure of cupola linings. Failure under load, spalling, and slag corrosion are briefly discussed.

B. M. Larsen and A. Grodner, *Factors affecting Open-Hearth Refractories* (Blast-Furnace and Steel Plant, 1927, vol. 15, Apr., pp. 161–164; May, pp. 217–220, 226). A careful study has been made of the effects of heat transfer and temperature on the behaviour of open-hearth refractories, the observations being taken at several open-hearth plants in the Detroit district, and checked where possible at the laboratory of

the Bureau of Mines. Such aspects as the mechanism of wear on a silica-brick arch during service, temperature changes in roofs and walls, temperature differences in the melting chamber, comparative temperature gradients in various walls, thermal efficiency and heat losses, critical working temperature range for the melting chamber, glazing of roof arch, local over-heating and hole formation in roof arch and walls, water-cooling of refractory walls, and insulation of walls and deteriorating effects on refractories are discussed, and the following conclusions are drawn: Irrespective of how much heat is lost through the walls of an O.-H. furnace, the inner surface temperatures must remain about the same to make possible a given rate of steel production. Any additional heat losses through walls must be made up by additional heat input from the combustion of fuel. Inner wall and bath temperatures are controlled essentially from within the furnace; thus, a roof arch is prevented from over-heating by radiating its excess heat on to a cooler bath, and a very thin air-cooled arch is never protected entirely from over-heating by air-cooling from outside. Except during the early melting period an O.-H. chamber cools and heats with a close approximation to black body conditions. With a silica roof such a chamber has a critical range of working temperatures of about 2725° to 2975° F. With less insulation, thinner walls, and better cooling outside, the temperature gradient from within to the outside is steeper and it is more difficult to overheat such walls; with better insulation, however, the risk of damage by spalling is decreased.

B. M. Larsen, *Some Notes on Open-Hearth Refractories* (Blast-Furnace and Steel Plant, 1927, vol. 15, June, pp. 295-296, 300). A comparison is made of different refractories for use in making banks and bottoms; the relative spalling resistances and non-corrosive properties of various bricks are discussed.

A. B. Searle, *Refractory Materials for Iron Foundries* (Fuel Economist, 1927, vol. 2, May, pp. 423-425).

A. B. Searle, *Refractory Materials for Reverberatory Furnaces* (Fuel Economist, 1927, vol. 2, June, pp. 489-491).

A. B. Searle, *Lining Materials for Blast-Furnaces* (Fuel Economist, 1927, vol. 2, July, pp. 547-551).

A. T. Green, *A Consideration of Open-Hearth Steelworks Refractories* (Paper read before the Ceramic Society, Sept. 1927: Iron and Coal Trades Review, 1927, vol. 115, Oct. 7, pp. 534-535). For all practical purposes an upper temperature limit of 1500° C. for the top courses of brickwork in the regenerator chambers was to be looked for, and if refractoriness alone be considered, the thermal properties of silica and fireclay products are notably outstanding. The influence of dusts, &c., had an important effect on the life of the chequerwork, and this had to be taken into account. The fluctuations of flame temperature and of velocity of gases should be minimised. Only 1 in. of the brickwork took part in the transmission of heat, and greater thicknesses than 2 in. (heated on both sides) were only required for stability. The losses from the regenerators by radiation and convection amounted

to 16 per cent. of the total heat losses of the steel plant, which was excessive, having regard to the fact that the thermal efficiency of the open-hearth process was only about 17 per cent. Insulation of the brickwork was thus very important, and the insertion of an insulating wall between the outer wall of red brick and the interior lining should reduce these losses to a minimum, and might considerably facilitate the even passage of the gases through the chambers.

For minimising wear and tear on refractories the producer gas and air should be adequately intermixed at the ports or in a spacing just following the ports, and they should be directed towards the bath at the centre of the furnace.

An investigation of the classes of silica bricks used in the open-hearth furnace indicates that many varieties are used, apparently with equal success. The silica bricks used in the steel industry generally contain an appreciable quantity of fragments up to 0.3 to 0.4 in. diam., and sometimes over. Coarse-grained products resist spalling better than fine-grained products of similar material. Hence coarser textures are better for the roofs of the furnaces—at any rate, if the original grading also includes a considerable proportion of the very fine or “flour” fraction. This latter determines the matrix formation and the alteration in the nature of silica, both of which occur at high temperatures. The matrix formation and the angularity of the larger particles mainly determine the strength of the product.

Examination of a number of bricks used in open-hearth furnaces show specific gravities ranging generally between 2.42 and 2.47, with a few over 2.50. Values of about 2.42 seem to be associated with bricks giving most satisfactory service.

E. Kothny, *Refractory Materials for the Electric Steel Furnace* (Feuerfest, 1927, vol. 3, Oct., pp. 157–164). Electric furnaces and the shapes of their hearths are classified, and the demands made on the structural materials used in their construction are reviewed. The refractories available for use in electric furnaces and the properties particularly required are enumerated. The properties of the individual refractories are discussed, and their behaviour in service is noted.

G. M. Carrie and C. F. Pascoe, *Magnesia Refractories for Steel Furnaces* (Paper read before the Second Empire Mining and Metallurgical Congress, Canada, 1927). The authors describe the properties and uses of magnesia, the various refractories available, the deposits of magnesia found in Canada and elsewhere, and the applications of magnesia refractories to open-hearth furnaces. They point out the importance of the development of better refractories, especially those used in the basic process.

O. Schweitzer, *Experiences with Steel Casting Ladles lined with Brickwork, Stamped Sand, and by the Torcrete Process* (Stahl und Eisen, 1927, vol. 47, June 16, pp. 998–1005). Comparative figures are given of the cost and maintenance of steel ladle linings. In the case of a 100-ton ladle serving an open-hearth furnace, a lining of good quality firebrick stood twenty tappings; the cost of firebrick, labour, and drying

with coke-oven gas amounted to £31·5, or about 4d. per ton of steel produced. For a similar ladle under the same conditions, lined with rammed kaolin sand, the life of the lining was twenty heats and the cost £17, or about 2d. per ton of steel produced. The same ladle lined with the liquid mass sprayed on, according to the torcrete process, had a life of five heats, with a cost of £5 for the lining, or 2½d. per ton of steel produced. The Hoesch Company, at whose works all these linings have been in practical use, had, however, a cheap material of their own which served for "torcreting" the ladle. By the use of this, the life of the lining was not more than three heats, but the cost of lining was only 36s., or about 1½d. per ton of steel produced. The torcrete method is, however, not always practicable, and the ramming with kaolin sand is therefore considered the most economical to adopt.

H. Küppers, *Rephosphorisation from Acid Ladle Linings made by the Torcrete Process (Refractory Spraying)* (Stahl und Eisen, 1927, vol. 47, July 7, p. 1142). Nine analyses of furnace and ladle samples were made at a Rhenish steelworks. The results show that no rephosphorisation had occurred in the ladle relined with acid material sprayed by the Torcrete process. Any convenient acid material is now used in steelworks employing this process, instead of ground brick or expensive refractory clay.

M. C. Booze, *Refractory Linings for Forge and Heating Furnaces* (Fuels and Furnaces, 1927, vol. 5, Sept., pp. 1197-1198). A brief discussion is given of various types of refractories best adapted for certain kinds of service in heating furnaces.

L. W. Briggs, *Experiences with Refractories in Furnace Construction* (Paper read before the American Refractories Institute, May 18, 1927; abstract, Blast-Furnace and Steel Plant, 1927, vol. 15, Aug., pp. 415-416).

W. J. May, *Refractory Materials for Metal Furnaces* (Mechanical World; Blast-Furnace and Steel Plant, 1927, vol. 15, May, p. 247). A few notes on the softening temperatures of refractories and bonds in common use and on some points to be observed in building and lining furnaces.

H. V. Corfield, *The Premature Holing of Silica Retorts* (Report on Refractory Materials by a Joint Committee of the Institution of Gas Engineers and the Society of British Gas Industries, 1927: Gas World, 1927, vol. 86, June 25, pp. 683-688). The author describes a number of failures of silica retorts. Iron was shown to be the cause of the trouble, but the manner of its introduction and of its action was not conclusively proved. The Report concludes with a paper by A. J. Dale entitled "Results of a Preliminary Laboratory Investigation of the Corrosion," in which tests to determine the cause are described, certain established facts are emphasised, and suggested remedies are put forward.

G. le B. Diamond, *Experiences of the Behaviour of Silica Retorts, with Special Reference to Slag Formation and Corrosion* (Gas World, 1927,

vol. 87, July 16, pp. 58-61). *Memorandum on the Corrosion of Silica Retorts* (Gas Journal, 1927, vol. 179, July 13, pp. 105-107). These articles were written as a supplement to the author's discussion on the Report noted on p. 484. He discusses spalling, jointing material, the cause of failure of joints and the preservation of joints, and puts forward a specification for silica jointing material.

Troubles of the Furnace Builders with Refractories. (Paper read before the American Refractories Institute, Atlantic City, May 18, 1927: *abstracts*, Blast-Furnace and Steel Plant, 1927, vol. 15, June, pp. 305-307; Forging, Stamping, Heat Treating, 1927, vol. 13, June, pp. 231-233). The conditions that exist in certain types of furnaces are considered, and the character of refractories that will meet these conditions are discussed.

H. Salmang, *Tests on the Slagging of Refractory Materials* (Stahl und Eisen, 1927, vol. 47, Oct. 27, pp. 1816-1820). To determine the effect of the constituents of slag on fireclay, they were allowed to work separately on a fireclay crucible. The slagging of the fireclay is dependent on the content of bases and the fluidity of the slag. The pure oxides have the most powerful effect in the order ferrous oxide, manganous oxide, lime, and magnesia. Then the basic, neutral, and acid silicates in that order. Phosphates dissolve fireclay almost as quickly as oxides. Ferric and manganic oxides have a less strong effect than the corresponding ferrous and manganous oxides. Complex silicates behave according to their content of bases.

R. A. Sherman and E. Taylor, *Service Factors Governing the Slagging of Boiler-Furnace Refractories* (Journal of the American Ceramic Society, 1927, vol. 10, Aug., pp. 629-643). Service factors, dependent on the type of coal burned and the method of burning, that are considered to govern slag erosion directly are: refractories temperatures, furnace gas temperatures, furnace gas compositions, furnace gas velocities, slag composition, and slag quantities. Values determined for part or all of these factors under each of the following sets of conditions are presented and their significance is discussed: eastern bituminous coals on underfeed stokers, powdered eastern bituminous coals in furnaces with extended radiant-heat absorbing surface, high-sulphur Pittsburgh coal on underfeed stokers, low-sulphur Pittsburgh coal on underfeed stokers, high-sulphur Pittsburgh coal on chain-grate stokers, Illinois coal on chain-grate stokers, and powdered Illinois coal.

S. J. McDowell, *A Laboratory Study of Slag Erosion* (Paper presented before the American Refractories Institute, Pittsburgh, Oct. 21, 1926: Blast-Furnace and Steel Plant, 1927, vol. 15, June, pp. 286-287). The article is a progress report of the Special Research Committee of the American Society of Mechanical Engineers on its investigation of the problem of slag erosion. The Committee is working in conjunction with the Fuel Division of the Bureau of Mines and the Columbus Branch of the Bureau of Standards. The objects of the investigation and the procedure to be adopted for future work are described.

FUEL.

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I.—CALORIFIC VALUE.

Calorimetry.—*The Scholes Bomb Calorimeter* (Engineering, 1927, vol. 123, Apr. 22, pp. 499–500). This calorimeter operates on conventional principles, but differs from the usual design in points of detail.

Fuel Technology.—G. B. Watkins, *Total Carbon in Coal* (Industrial and Engineering Chemistry, 1927, vol. 19, Sept., pp. 1052–1054). A mercury-sealed gasometer suitable for measuring the volume of the gaseous products of combustion from heating value determinations of coal and combustible organic compounds is described. The carbon dioxide content of these products is determined and the total carbon calculated. Five different coal samples and benzoic acid and sucrose were exploded in a bomb and temperature-time readings recorded. The products of combustion were then released into the gasometer and their volume was measured at about atmospheric pressure. Samples of gas were withdrawn from the gasometer, and carbon dioxide was determined by absorption in caustic solution. The time required for the total carbon determination is less than half an hour after the completion of the heating value test.

J. T. Ward and J. B. Hamblen, *Influence of Diffusion of Oxygen on the Rate of Combustion of Solid Carbon* (Industrial and Engineering Chemistry, 1927, vol. 19, Sept., pp. 1025–1027). The conclusions reached are that when solid carbon burns the controlling variable is not the rate of chemical interaction of carbon and oxygen, but is the rate of diffusion of the combustion gas through the gas film.

H. Davies and H. Hartley, *The Examination of the Products of Combustion from Coal-Gas Flames* (Journal of the Society of Chemical Industry, 1927, vol. 46, June 3, pp. 201–206T). The investigation described consists in the simultaneous determinations of the carbon monoxide in the products from coal-gas flames and that in the air of the

laboratory. The iodine pentoxide method was used for the research; flames burning in the air of an ordinary room were found to emit traces of carbon monoxide, and the concentrations of carbon monoxide in the undiluted dry products of combustion were calculated.

The Coal-Treatment Laboratory: Birmingham University (Engineering, 1927, vol. 123, June 24, pp. 753-757 and 4 plates). A well-illustrated description of the equipment of the laboratory is given.

R. Stumper, *Influence of Ash Content on the Calculated Calorific Value of Ash-Free Coal* (Brennstoff Chemie, 1927, vol. 8, pp. 261-262).

R. V. Wheeler, *The Chemistry of Coal* (Paper read before Section G of the British Association, Sept. 2, 1927: Gas Journal, 1927, vol. 179, Sept. 14, pp. 624-626; Engineering, 1927, vol. 124, Sept. 9, pp. 344-346).

F. Fischer, *Twelve Years of Research on Coal* (Zeitschrift für angewandte Chemie, 1927, vol. 40, Feb., pp. 161-165; Chimie et Industrie, 1927, vol. 17, Mar., pp. 367-374). This paper was presented at a meeting of German chemists held on Sept. 25, 1926, at the Kaiser-Wilhelm Institut für Kohlenforschung at Mülheim-Ruhr, and in it the author reviews the work carried out at that Institution since its inauguration on July 27, 1914.

Liquefaction of Coal.—*The Bergius Process for the Hydrogenation of Coal* (Neue Deutsche-Bergbau-Zeitung, No. 25, 1926; Fuel, 1927, vol. 6, May, pp. 213-216). An account of the development of the Bergius process for the hydrogenation of coal is given, describing its progress since the experimental stage. An intermittent process was first developed, but this may be ruled out in carrying on the work on a large scale. The frequent opening of the reaction vessel, the release of the pressure, the cooling and reheating, would make the process too expensive and wasteful for any work on a large scale. The following is a brief account of the continuous process as carried out at the Bergin-Werk at Mannheim-Rheinau: The coal (ground to a size of about 1 mm.) is made into a paste by mixing with it a certain proportion of oil, for example, a coal-tar from which the lighter oils have been removed. By means of a special high-power pump this paste is forced into the heating vessel of the high-pressure plant, together with the necessary quantity of hydrogen, at a pressure of 150 atm. This heating vessel is provided with a mixing device. From the heating vessel the mixture passes into the reaction vessel proper and remains there until hydrogenation is complete, when the products pass into the cooling and condensing plant, and finally into a special collecting vessel, where the separation of the liquid and gaseous products is effected. The gaseous products pass into a gasholder, and the liquid products containing the oil, the water formed during the reaction, the portion of the coal which has escaped hydrogenation, and the ash, are run off through a special valve to undergo subsequent treatment. An oil yield of 50 per cent. of the coal used can be obtained. An important consideration is that

the hydrogen for the process is produced by the process itself. About two-thirds of the gases, containing methane, which are given off during the process, are used for the preparation of the hydrogen. A particular advantage of the process is that it does not require a special catalyst. Hence sulphur, which is always present in coal, has no harmful influence on the process. Furthermore, the Bergius process of hydrogenating coal is not obliged to rely on supplies of high-grade coking coals as a source of its raw material, but can use to advantage low-grade coals and non-coking slack. Large supplies of such coal are available in all coal-producing countries, so that the Bergius process is guaranteed a practically inexhaustible supply of raw material.

C. Krauch, *Technical and Economic Considerations of Coal Enrichment and Transformation, with Special Reference to High-Pressure Processes* (Stahl und Eisen, 1927, vol. 47, July 7, pp. 1118-1126). The paper deals, first, with the Haber-Bosch process and its technical difficulties. The preparation of the necessary gases and the transformation of ammonia into solid manure are described. These factors are of greater importance than the high-pressure synthesis itself. Technical improvements in these factors have enabled the prices of synthetic fertilisers to be lowered below pre-war figures, thus rendering possible a tremendous increase in the home consumption of these products for agricultural purposes and also a considerable export. The second part of the paper deals with the liquefaction of coal and its dry distillation. The latter enables liquid products to be formed through carbon monoxide and hydrogen with the assistance of catalysts. The synthesis of methanol and higher alcohols followed from the discovery at Ludwigshafen in 1913 that higher hydrocarbons and oxyderivatives could be obtained by the catalytic hydrogenation of CO, and not methane only, as had always previously resulted. Reference is made to the direct hydrogenation of coal culminating in Bergius' evidence that hydrogen may be united to coals of various origins and that liquid products result. The I.G. process, now the subject of large-scale plant trials at Leuna Works, aims at the production, by means of pressure hydrogenation and catalysts, of definite products. Although these synthetic products compete with the mineral oils, the latter may eventually take advantage of the new processes. The I.G. process is also attempting to apply technically such reaction accelerators as electric fields, discharges, and accurately limited ranges of radiant energy.

J. P. Arend, *The Liquefaction of Coal* (Revue Technique Luxembourgeoise, 1927, vol. 19, No. 5, pp. 131-138). Much of the paper is devoted to the preparation of hydrogen, catalysts, the effects of high pressures on reacting gases, and the fixation of atmospheric nitrogen, but the last three pages give a brief description of the Bergius process and a comparison of that process with the Fischer-Tropsch method of liquefying coal.

J. B. C. Kershaw, *The Bergius Process of Coal Liquefaction* (Colliery Engineering, 1927, vol. 4, May, pp. 193-197). An illustrated account

is given of the plant operated at the experimental works at Rheinau on the Rhine.

A. Spilker and K. Zerbe, *Study of the Chemical Phenomena which Occur During the Hydrogenation of Coal by the Bergius Method* (Zeitschrift für angewandte Chemie, 1926, vol. 39, Sept. 30, pp. 1138-1143).

Pulverised Fuel.—*Powdered Coal and Gas Cleaning* (Iron Age, 1927, vol. 119, May 19, pp. 1443-1446). An illustrated account is given of the powdered-coal plant and the gas-cleaning plant at the works of the Colorado Fuel and Iron Co., Pueblo, Colorado. The coal-pulverising equipment includes three rotating ball-screen type mills with a capacity of 6 tons per hour each. There are one indirect fired coal dryer, two 6-in. Fuller-Kinyon pumps, one 50-ton raw coal bin, and one 40-ton dried coal bin. The gas-cleaning plant is operated on the Cottrell electrical precipitation principle. While the cleaned blast-furnace gas contains an average of 0.2 grain of dust per cu. ft., this figure can be reduced by slowing the flow of gas through the precipitators. The gas is cleaned without reducing the temperature, which adds about 3 per cent. to its heating value. Absence of moisture provides a better gas for combustion, and eliminates the necessity of flushing or washing out the gas mains or burners. The dry dust is easily handled, flows by gravity from the precipitators to cars, and is in an ideal condition for sintering and returning to the furnaces. The power required for operating the gas-cleaning plant totals 80 kw.

C. H. S. Topholme, *Pulverised Fuel Plant at Pooley Hall Colliery* (Colliery Guardian, 1927, vol. 135, Nov. 4, pp. 917-919). Particulars are given of the utilisation of pulverised fuel under boilers by means of the Attritor system.

R. H. Irons, *Powdered Coal for Plate Mills* (Iron Age, 1927, vol. 120, Aug. 25, pp. 469-471). An illustrated description is given of the layout of the coal-pulverising plant of the Central Iron and Steel Co., Harrisburg, Pa.

P. Rosin, *Characteristics of the Pulverised Brown-Coal Furnace* (Fuel Economist, 1927, vol. 2, July, pp. 539-544). The author discusses German practice in the use of pulverised brown-coal for steam raising.

C. H. S. Topholme, *Air-Swept Combination Ball and Tube Mills for Pulverising Coal* (Iron and Coal Trades Review, 1927, vol. 114, June 17, p. 961). Brief illustrated particulars are given of the Kennedy combination mill for pulverised coal.

D. L. Mekeel, *A Steel Mill Boiler Plant* (Paper read before the American Iron and Steel Institute, Oct. 1927). The author describes the new boiler plant at the South Mills of the Aliquippa Works of the Jones and Laughlin Steel Corporation, Pittsburgh. The plant contains a single row of five boilers of 1900 nominal H.P. to operate normally at about 200 per cent. of rating. The boilers are fired with pulverised coal.

Pulverised Fuel Developments in America (Fuel Economist, 1927, vol. 2, Sept., pp. 665-666). The progress which is being made in America with this system of firing and the improvements which are being introduced are indicated.

Fuel Economy.—H. Lent, *The Development of Heat Economy in the Iron and Steel Industry* (Stahl und Eisen, 1927, vol. 47, July 21, pp. 1189-1196). The heat requirement per ton of steel in present-day practice is about one-quarter of that needed for direct reduction in the sixteenth century. The heat requirement per ton of product has steadily decreased for pig iron and open-hearth steel; for the latter a figure of 10^6 kg. cal./ton has recently been maintained over long periods. The use of coke-oven blast-furnace gas mixtures, large outputs, study of combustion processes, and better management have rendered this economy possible. The use of blast-furnace or mixed gas and wide electrification have also enabled the consumption of coal for reheating and power to be reduced to very low figures. The effect of output on the consumption of heat per unit for power or product is shown in a series of interesting curves. Reductions of 20 to 30 per cent. in heat consumption are shown in the last eight years for three Rhenish-Westphalian works. Further research on heat transfer and combustion processes is necessary; additional co-operative effort and exchange of views will lead to reduction of other avoidable losses.

H. A. Brassert, *Fuel Economy in the Iron and Steel Industry* (Paper read before the Eastern States Blast-Furnace and Coke Oven Association, Mar. 4, 1927: Fuels and Furnaces, 1927, vol. 5, Apr., pp. 467-471). The author discusses the more economical use of fuels: proper application of fuel, cleaning of gas, gas enrichment, use of preheated air, and effect of gas constituents on heat transmission.

E. F. Entwisle, *Possibilities of Fuel Economy* (Iron Age, 1927, vol. 120, Aug. 18, pp. 397-399). The author presents tables showing approximately the surplus heat production from coke-ovens and blast-furnaces for two types of plants—(a) in which the whole of the steel is made by the Bessemer process, and (b) in which 20 per cent. of the steel is produced by the Bessemer process and 80 per cent. by the open-hearth process. Particulars are also included of the total amount of heat necessary to carry on the various operations of steel-making, heating, and rolling.

O. P. Hood, *American Fuel Resources* (Paper read before the American Society of Mechanical Engineers, Fuels Division, Oct. 10-13, 1927: Mechanical Engineering, 1927, vol. 49, Oct., pp. 1061-1062). The author points out the growing appreciation of the value of fuel, and discusses the various fuel resources, indicating that solid fuels are the main source of energy. He states that the coal resources economically available are less than is usually believed, and comments on the passing of anthracite as a commercial fuel.

M. H. Mawhinney, *Practical Industrial Furnace Design* (Forging,

Stamping, Heat Treating, 1927, vol. 13, May, pp. 181-185; July, pp. 271-275; Aug., pp. 320-325). A continuation of a series of articles (see Journ. I. and S.I., 1927, No. I. p. 828). In the present series the author discusses the factors which influence fuel consumption in all types of furnaces, both from the theoretical and practical standpoint, the several channels through which heat is lost, calculations for electric furnaces, rates of heating and methods of saving heat, and the construction of a furnace, with notes on various features in design which are of major importance.

J. W. Cobb, *The Utilisation of Our Coal Supplies* (Paper read before Section G of the British Association, Sept. 2, 1927: *abstract*, Engineering, 1927, vol. 124, Sept. 9, pp. 341-342).

C. H. Lander, *Our Available Coal Supplies and their Utilisation* (Paper read before Section G of the British Association, Sept. 2, 1927: *abstract*, Engineering, 1927, vol. 124, Sept. 2, pp. 340-341).

Utilisation of Waste Heat.—A. J. Ebner and J. C. Hayes, *Results of Tests on Waste-Heat Boilers* (Blast-Furnace and Steel Plant, 1927, vol. 15, Apr., pp. 191-192; Freyn Design, 1927, Feb., pp. 19-20). A description of an installation of waste-heat boilers on three 90-ton O.-H. furnaces at the South Division Plant, Canton, Ohio, of the United Alloy Steel Corporation. Each unit comprises a boiler, superheater, auxiliary oil-fired combustion chamber, induced draught fan, and flue and stack connections with dampers and valves. Provision is made for firing the boilers directly by oil to provide steam when the furnaces are out of operation. The operating figures after nine months' operation are given.

A. J. Ebner, *Waste-Heat Boiler Applications* (Combustion, June, 1927; Blast-Furnace and Steel Plant, 1927, vol. 15, July, pp. 350-351, 355). The author notes briefly the history of waste-heat boilers, and indicates the particular features which they must incorporate. He then discusses the relative merits of fire-tube and water-tube boilers for the utilisation of waste heat, and records the results obtained in practice with fire-tube boilers.

C. A. Kelsey, *Heat Balances in Industrial Plants* (Paper read before the Western Society of Engineers, Chicago, January 31, 1927: Blast-Furnace and Steel Plant, 1927, vol. 15, Apr., pp. 193-197). The author discusses the utilisation of waste heat and waste steam and the economies which will result; he deals with his subject from the economic point of view.

A. N. Conarroe, *Utilisation of Waste Heat for Steam Generation* (Freyn Design, 1926, vol. 1, Apr., pp. 14-16). Particulars are given of the utilisation of waste heat from open-hearth furnaces at the plant of the National Malleable and Steel Casting Co. High velocity fire-tube boilers are installed beneath the charging floors of the furnaces. Before the installation of the waste-heat boilers it was customary to use two boilers in the power house, one of 260 B.H.P. and one of

400 B.H.P. during the winter months, and one of 400 B.H.P. during the summer months. With one open-hearth furnace operating with a waste-heat boiler, it was possible to run the power house with one 400 B.H.P. boiler most of the winter. During the summer months a 260 B.H.P. boiler was operated alone, being banked at night and operating during the day. Due to increased draught, the number of heats from the open-hearth furnaces was increased by 20 per cent.

F. J. Taylor, *Raising Steam by Waste Heat* (Colliery Guardian, 1927, vol. 135, Oct. 14, pp. 617-621). The production of steam by gas-fired or waste-heat boilers and other means of utilising waste heat are considered. In order to ensure really efficient heat transmission in the case of waste-heat boilers, the tubes must either be closely spaced in the case of a water-tube boiler, or of small diameter in the case of a fire-tube boiler, because it is of vital importance for the gas to have a high velocity. This is necessary to ensure a positive scrubbing action, and the velocity must be sufficiently high to break up the definite stream lines along which the gas tends to flow. If such conditions be permitted, there tends to form a hot core with a film of cool gas, acting as a heat insulator, next the tubes. The boiler must be properly proportioned for a high rate of heat transfer and low draught loss. A water-tube boiler with a given gas velocity and tube diameter has a higher heat transfer rate than one of the fire-tube type, but the latter sets up less frictional loss, so that a high gas velocity is permissible and the rate of heat transfer is high.

J. B. Crane, *Waste-Heat Boiler Application* (Blast-Furnace and Steel Plant, 1927, vol. 15, Sept., pp. 448-449, 453). A concise account of the economic and practical considerations entering into the selection and installation of boilers for the recovery of waste heat.

II.—COAL.

Canada.—F. Glover, *The Coalfields of British Columbia* (Colliery Engineering, 1927, vol. 4, Sept., pp. 350-356). The author reviews the coal-mining industry of British Columbia, and includes brief descriptions of the various coal areas.

W. S. Dyer, *Minto Coal Basin, New Brunswick* (Canada Geological Survey, 1926, Memoir No. 151). The report gives detailed information respecting the geology and coal resources of the basin.

China.—H. C. Tan, *Geology of the Pa Tao Hao Coalfield in the Hei Shan District*, W. Fengtien (Bulletin of the Geological Survey of China, Dec. 1926, No. 8, pp. 20-29).

H. C. Tan, *Geology of the Pei Piao Coalfield, Chao Yang District, Jehol* (Bulletin of the Geological Survey of China, Dec. 1926, No. 8, pp. 30-32).

W. H. Wong, *Classification of Chinese Coals* (Bulletin of the Geological Survey of China, Dec. 1926, No. 8, pp. 33-55). A systematic classification of Chinese coals has been attempted, and a new system of nomenclature and notation is outlined.

England.—T. H. Whitehead and T. Eastwood, *The Geology of the Southern Part of the South Staffordshire Coalfield* (Memoirs of the Geological Survey of England and Wales, 1927. London: H.M. Stationery Office).

Spain.—P. Kukuk, *The Asturian Coal Deposits in the Cantabrian Cordilleras* (Glückauf, 1927, vol. 63, June 4, pp. 821-829). Following a short review of the coal formations in Spain, a description of the Asturian coal district is given, with plans and stratigraphic sections showing the geological structure of the coalfield. Particulars are given of the character of the coal, ownership of the mines, and the economic conditions of the coal-mining industry.

Transvaal.—E. Krenkel, *The Coalfields of the Transvaal* (Glückauf, 1927, vol. 63, Apr. 30, pp. 637-645). The geological structure, extent, and character of the coal seams in the Witbank and Springs-Heidelberg districts are discussed.

Wales.—A. Howell, *The Correlation of the Coals of the Lower Coal Series in the East Glamorgan and Monmouthshire Coalfield* (Proceedings of the South Wales Institute of Engineers, 1927, vol. 43, pp. 321-380).

A. Strahan and W. Gibson, *The Geology of the South Wales Coalfield. Part 2.—Abergavenny*, Second Edition (Memoirs of the Geological Survey of England and Wales, 1927. London: H.M. Stationery Office).

United States.—J. E. Lamar, *Preliminary Report on the Economic Mineral Resources of Calhoun County* (Illinois State Geological Survey: Report of Investigations, No. 8). The geological structure and stratigraphy of the deposits are described, and the economic resources, including limestone, coal, oil, and gas, are discussed.

Weathering of Coal.—J. H. H. Nicolls, *Effects of Continued Weathering upon the Friabilities of Various Fuels* (Canada Department of Mines, Mines Branch, Investigations of Fuels and Fuel Testing, 1925, pp. 101-105). Tables are presented showing the effect of weathering on Canadian coals and lignites.

T. E. Layng and A. W. Coffman, *Effect of Weathering on the Softening and Solidification Points of Coal* (Industrial and Engineering Chemistry, 1927, vol. 19, Aug., pp. 924-925).

Constitution of Coal.—E. Stach, *The Origin of Fusain* (Glückauf, 1927, vol. 63, May 21, pp. 759–763; Fuel, 1927, vol. 6, Sept., pp. 403–410). Methods of preparing coal to develop the structure of fusain are described, and micrographs of specimens are well illustrated. In explaining the formation of fusain, the theory of forest fires must be discarded. It is assumed from its fine state of dispersion, and the different states of preservation in which it survives, that fusain was formed from wood impregnated with ulmic substances, which has undergone a process of formation into coal different from that of the wood substance which became vitrain.

The Banded Constituents of Coal (Gas World, Coking Section, 1927, vol. 87, Nov. 5, pp. 138–140). A consideration of the extent to which the existence of greater or lesser proportions of each of the banded constituents—fusain, durain, clarain, vitrain—will modify the behaviour of a coal on carbonisation, how they affect the coking power of coal, the nature of the volatile products, and whether they contribute distinctively to the character of the ash.

J. Lomax, *The Preparation and Examination of Coal Sections* (Journal of the Royal Microscopical Society, 1927, vol. 47, Sept., pp. 239–249). The author describes the technique of the preparation of thin, transparent sections of coal samples for examination under the microscope.

W. P. Evans, *Microstructure of New Zealand Lignites* (New Zealand Journal of Science and Technology, 1927, vol. 9, May, pp. 11–21). The author describes and compares the “sectioning” and “etching” methods for the study of the microstructure of coal, and reports the results obtained by him in his investigation of the New Zealand lignites. The work done so far points to two main features in the South Island lignites—namely, a preponderance of coniferous woods, and a comparatively rare occurrence of spores. Sixteen micrographs accompany the paper.

III.—COKE.

Coke-Oven Plant.—*New By-Product Coke-Oven Plant at the “A” Winning Colliery of the Blackwell Colliery Company, Ltd.* (Iron and Coal Trades Review, 1927, vol. 115, July 22, pp. 128–131). A detailed illustrated account is given of the layout and equipment of the Koppers regenerative taper ovens at this colliery, designed for carbonising the coal under compressed conditions. The new installation consists of a battery of forty ovens, together with complete by-product plant. There is also a coal-screening plant and a Hunter-Baum coal-washer. The oven chambers are of silica brick, and are 8 ft. 6 in. high, 32 ft. 2 in. long by 18 in. wide. They take a charge of $9\frac{1}{4}$ tons of wet coal, and the coking period is about $21\frac{1}{2}$ hrs. The coke is discharged from

the ovens through a guide into trucks, and is conveyed to a central quenching station.

Orgreave Coking Plant (Iron and Coal Trades Review, 1927, vol. 115, Aug. 19, pp. 257–261). The Orgreave coking plant of the United Steel Companies is illustrated and described in detail. The carbonising plant consists of 108 ovens of the Koppers combination type, arranged in two batteries. The oven chamber is 33 ft. long, 8 ft. high, and $20\frac{1}{2}$ in. in width. At present the ovens are heated by coal-gas, but provision is made to install a battery of gas-producers. The total capacity of the ovens is about 6000 tons per week. The coke is discharged through a Derby quencher, but final quenching is done by sprays at the end of the batteries. The coke is pushed out of the ovens into a coke car 50 ft. in length, the floor of which slopes away from the ovens so that the coke can slide from the car by gravity. The description includes an account of the by-product, crude benzol, and tar distillation plants.

The Becker Coke-Oven (Gas Journal, 1927, vol. 180, Oct. 26, pp. 253–255). An illustrated description of the Becker coke-oven plant at the Usines de Chatelineau, Charleroi, Belgium.

R. Gunderson, *An Important Development in Coke-Oven Design* (Colliery Engineering, 1927, vol. 4, Aug., pp. 313–319). The author outlines recent progress in coke-oven design, with special reference to the Still coke-oven.

R. A. Mott, *The Historical Development of the Design of the By-Product Oven* (Fuel, 1927, vol. 6, Aug., pp. 373–380). A brief historical note on the coking of coal is followed by an account of the development of the by-product coke-oven.

G. M. Gill, *Ovens as a Gasworks' Carbonising Plant* (Paper read before the Institute of Gas Engineers, 1927 : Gas Journal, 1927, vol. 178, June 22, pp. 880–891 ; Gas World, 1927, vol. 86, June 18, pp. 633–644). Several types of coke-ovens are described, with notes on their operation.

F. D. Harper, *Starting an Old Coke-Oven Plant* (Gas World, Coking Section, 1927, vol. 87, July 2, p. 72). The author describes the re-starting of a coke-oven plant which had been shut down. He considers that when a prolonged period of inactivity has to be faced the best policy is to shut down completely, and not to try to keep the ovens hot by "bee-hiving" the coke ; during the shut-down the ovens can be put in thorough working order, and the coke which would be used for keeping the ovens hot is available for heating up when work is restarted.

Manufacture of Coke.—H. Kuhn, *The Uniform Heating of Coke-Ovens* (Fuel, 1927, vol. 6, June, pp. 267–277 ; July, pp. 318–331). For many years designers of coke-ovens have aimed at means to obtain uniform heating of the charge throughout the height of the coke-oven chamber. In the ordinary vertical flue oven, the lower portions of the

flue are more intensively heated by the combustion of the gas than the upper portions exposed only to the burnt gases; consequently, there is a considerable drop in the temperature of the heating surface and of the whole wall from the bottom upwards, with a corresponding drop in the amount of heat transferred to the charge. Modifications have been made from time to time to remedy this defect, such as the introduction of the taper oven, the thickening of the lower part of the heating wall, heating by waste gas, vertical flues beginning at different heights, that is, alternately on a level with the oven sole and at a certain distance above it. Better results have been obtained by arranging the heating flues horizontally and admitting the gas in several stages. A greater improvement is obtained by the use of vertical flues with admission of air at several ports situated one above the other in the flue and fed by small vertical channels in the masonry between the flues, which are fed with air from the sole flue. The gas then burns in several stages throughout the vertical length of the flue. The various upward burning flames overlap and produce a continuous flame extending from the sole to the roof, the air ports being so designed that the combustion of the gas is incomplete at each stage, except at the top, where it is completed. An oven of this type is now at work at Thionville, in France, and measurements on the ovens show that the vertical differences of temperature of the heating wall average between 5° and 10° C., a variation of 0.5 to 1 per cent., the coking temperature being about 1050° C.

R. Bulmer, *Notes on the Manufacture and Use of Metallurgical Coke* (Bulletin of the British Cast Iron Research Association, 1927, July, No. 17, pp. 19–20). The author deals briefly with the properties of metallurgical coke from the two standpoints—(a) chemical composition, and (b) physical characteristics.

Feodoroff, *Balance-Sheet of the Coke-Oven Gases from the Coke-Ovens at Routchenkovo* (Chimie et Industrie, 1927, vol. 17, May, pp. 729–736). The coke-oven plant, its operation, the results obtained, and the distribution of the resulting gas are described.

R. A. Mott, *Progress in Research on the Properties of Coke for Blast-Furnace Use* (Fuel, 1927, vol. 6, June, pp. 244–251). Notwithstanding many improvements in coke-oven design and in the mechanical operation of coke-oven plants, comparatively little attention has been paid to the improvement of the quality of the resultant coke. The chief factors which have received attention are the fineness of grinding the coal charged to the ovens, and the rate of heating. It is known that the finer the crushing the more uniform is the distribution of the thin flakes of shale, which often remain after washing and reduce the mechanical strength of the coke. It is also known that the faster the rate of heating the better is the quality of coke made from poor coking coals, but the effect of an increased rate of heating on strongly coking coals is not so well known. The two most important qualities desirable in a blast-furnace coke are mechanical strength and combusti-

bility under blast-furnace conditions. For testing the strength a shatter test has been devised, and the method of carrying it out is illustrated and described. For the combustibility test, an experimental furnace has been erected under the auspices of the Blast-Furnace Coke Research Committee.

R. A. Mott, *A Study of Coke Formation* (Fuel, 1927, vol. 6, May, pp. 217-231). The first stage of coke formation in a coke-oven is the expulsion, possibly extrusion, from the coal of some volatile matter which binds together the coal particles into a loosely coherent mass. The second stage appears to be one of apparent liquefaction in which the loosely bound coal particles lose all semblance of their original shape and give a more or less porous structure. The author's research deals particularly with these two stages of coke formation. There is no direct evidence to show that more than 10 to 15 per cent. of the coal substance can be obtained as liquid products during carbonisation, and the apparent liquefaction of a coking coal may perhaps be accounted for by the theory of surface flow of solids. It is suggested that the solid surfaces of a coking coal may flow under mechanical disturbance due to gas pressures developed inside individual coal particles, aided by solvent action of the liquid products of decomposition, and, to a smaller extent, by the passage of gas through the coke-forming mass. A second phase of coke formation is the binding together of the individual fine particles of coal to form a coherent aggregate. In both phases, internal gas pressure, causing swelling of the coal, is an important factor. The greater the gas pressure, the greater would be the extent of vitrification and the mechanical strength of the coke produced.

E. Audibert and L. Delmas, *Contribution to the Study of the Mechanism of the Transformation of Coal into Coke* (Paper read before the Société de Chimie Industrielle, Dec. 1, 1926: *Chimie et Industrie*, 1927, vol. 17, Mar., pp. 355-366; May, pp. 707-722).

D. J. W. Kreulen, *Researches on the Agglutinating Power of Coal* (*Chemisch Weekblad*, 1926, vol. 23, Oct., pp. 449-454). The author has sought to find a relationship between the agglutinating power of a coal and the texture of the inert materials with which it might be mixed; in particular he studied the behaviour of the same kind of coal under a certain treatment when mixed with inert matter of various degrees of fineness, and when mixed with different inert materials all of the same texture. He found that if inert matter of different grain sizes be added to the coal, the compressive strength of the coke is improved progressively by decreasing the size of the grains until a maximum is attained. The nature of the inert material was of notable importance. The author also studied the effect of the addition of lean coal, in larger or smaller pieces, to coking coal.

J. Van de Waerden, *An Examination of the Netherlands East Indian Coals* (Fuel, 1927, vol. 6, June, pp. 252-256). The article is a summary of an official report on coking tests carried out on several kinds of Netherlands East Indian coal. The deposits belong, with a single

exception, to the tertiary formation. The caking capacity of the coal is very low.

F. S. Sinnatt, A. McCulloch, and H. E. Newall, *The Carbonisation of Particles of Coal; the Study of Cenospheres*.—IV. (Fuel, 1927, vol. 6, Sept., pp. 398–402). The influence of various atmospheres upon the structure of cenospheres is described. Reduction of pressure and, to a smaller extent, an atmosphere of steam, inhibit the formation of the typical cenosphere window and lattice structure, appearing to allow of the escape of the gas produced during the decomposition of the coal. This does not appear to occur in the case of the cenospheres produced in nitrogen, coal-gas, or hydrogen; the gas produced distends the particles to form cenospheres. In mixtures made with increasing quantities of electrode carbon the cenospheres produced from coal and electrode carbon become reduced in size, and the structure is also modified. Pulverisation and briquetting appear to cause the formation of small cenospheres within a larger particle, so that the larger particle presents the appearance of a blackberry, the surface being covered by protuberances, each of which appears to be an individual cenosphere, either fully formed or in formation.

J. G. King and R. E. Willgress, *The Primary Decomposition of Coal* (Department of Scientific and Industrial Research: Fuel Research Board, 1927, Technical Paper 16). This report covers part of a new series of investigations, which is being carried out at the Fuel Research Station, into the behaviour of coal on heating and on the products of distillation. The authors describe the methods used and the results obtained, and give a brief survey of the results obtained by previous investigators.

J. Roberts, *The Initial Decomposition of Coal* (Colliery Engineering, 1927, vol. 4, July, pp. 281–282). A brief review is given of researches of different investigators on the temperatures at which fuels show signs of initial decomposition.

L. K. Ramsin, *The Resistance of Materials to Gas Flow* (Fuel, 1927, vol. 6, Sept., pp. 411–415). The research was carried out at the U.S.S.R. Thermo-Technical Institute, Moscow, and the materials used for the tests were anthracite screenings, maize, wheat, and poppy-seed. The anthracite grains were passed through sieves of 5 to 8 mm., the average size of grain being 6.5 mm. Further tests were made with anthracite passed through sieves of 2 mm. with an average grain-size of 1 mm. The particles were of an irregular form, with sharp angles. The experiments show that the resistance to the flow of gas through the material increases in direct proportion to the thickness of the layer.

Schweder, *Improvement of Coke by Grinding the Coal* (Gas- und Wasserfach, 1927, vol. 70, pp. 710–712). Tests on coke produced from unground and ground coal show that coke from ground coal contains a much smaller proportion of small coke and breeze, the gas yield remaining unchanged. The coke is still further improved by suitable blending of coal.

H. Müschenborn, *Schramm's Laboratory Method for Determining the Yields of Coke and By-Products from Coal, and its Importance in Coking Practice* (Brennstoff Chemie, 1927, vol. 8, pp. 138-140). A description of the method is given, and the yields are found to be in close agreement with those found in actual coking practice.

G. E. Foxwell, *The Formation of Coke* (Gas World, Coking Section, 1927, vol. 86, June 4, pp. 60-64). The author discusses the mechanism of the formation of coke during coal carbonisation.

G. E. Foxwell, *Early Theories of Coking* (Gas World, Coking Section, 1927, vol. 87, Aug. 6, p. 80).

G. E. Foxwell, *Review of Coke-Oven Technology in 1926* (Fuel Economy Review, 1927, vol. 6, pp. 23-26).

Coke Quenching.—A. M. Beebee, *A Dry Quenching Coke Plant* (Paper read before the Eastern States Blast-Furnace and Coke-Oven Association, Mar. 4, 1927: Fuels and Furnaces, 1927, vol. 5, Apr., pp. 455-459). The coke-quenching plant in operation at Rochester, N.J., is described, and particulars of operating results are included.

A. M. Beebee, *Advantages and Disadvantages of the Dry Quenching of Coke* (Paper read before the Canadian Gas Association, June 1927: Gas World, Coking Section, 1927, vol. 87, Aug. 6, pp. 83-85).

J. P. Leather, *Dry Cooling of Coke* (Paper read before the Institution of Gas Engineers: Iron and Coal Trades Review, 1927, vol. 114, June 17, pp. 962-963). The author describes various systems of dry-cooling coke, including the Sulzer and Collin processes. The chemical reactions involved in these processes are also considered.

O. Trinquet, *The Quenching of Coke in Coke-Oven Plants* (Génie Civil, 1927, vol. 91, Aug. 13, pp. 157-161). A description of the Sulzer coke-quenching plant at the Homécourt Steelworks, Meurthe-et-Moselle.

P. Mougin, *Modern Methods of Coke Cooling in Gas-Works* (Paper read before the Annual French Gas Congress, 1927: abstract, Gas Journal, 1927, vol. 179, July 13, pp. 95-96; July 20, p. 165).

Properties of Coke.—W. Melzer, *Causes of the Sluggish Ignition of Dry-Quenched Coke* (Berichte der Gesellschaft für Kohlentechnik, 1926, No. 7, p. 33; Stahl und Eisen, 1927, vol. 47, May 5, pp. 759-760). Tests were made on samples of coke cooled by water-spraying, by burying in dry moulding sand, by dry-quenching by treating with carbon dioxide, and by spraying the hot coke with concentrated ammonia solution. The results confirm Hausser's conclusions that dry-quenched coke is certainly more difficult to ignite than coke quenched by liquid agents, but the exact reason why is not easy to ascertain.

G. Agde and H. Schmitt, *Reactivity of Coke* (Brennstoff-Chemie, 1927, vol. 8, pp. 121-123). The reactivity of coke principally depends on the possibility of contact of its carbon, particularly amorphous carbon, with carbon dioxide. This is determined by the specific number,

form, and diameter of the pores in the surface of the coke which are accessible to the gas without unduly prolonged diffusion. The principal factors in determining this are the character of the original coal and the degree of decomposition of the tar coke, corresponding to the carbonising temperature.

G. Agde and H. Schmitt, *The Estimation of the Reducing Power of Hard Coke* (Stahl und Eisen, 1927, vol. 47, Sept. 8, pp. 1477-1481). Recent research on blast-furnace practice shows the importance of the reactive properties of coke. The question of a laboratory test to ascertain its reducing power arises. The scientific basis for such a test and a method of working it are described. It depends on the determination of the velocity with which equilibrium is attained in the CO_2 -CO reaction, but, in addition, the temperature at which CO_2 commences to react with coke and the speed of gasification of coke in CO_2 are determined. Indications are given as to a basis for the valuation of coke.

G. Agde, *Combustibility, Reactivity, or Reduction Capacity* (Glückauf, 1927, vol. 63, Aug. 27, pp. 1267-1270). To avoid confusion in the use of several terms employed to define certain chemical characteristics of coke, the author recommends that the term "reactivity" is the most suitable to adopt in place of all others, on the ground that the speeds of reaction of different cokes with oxygen and carbon monoxide differ considerably.

T. L. Joseph, *Behaviour of Coke in the Blast-Furnace—A Review* (Paper read before the American Iron and Steel Institute, Oct. 1927). The author discusses the meaning of the term "combustibility," and reviews the various tests which have been proposed for measuring the combustibility of coke. The investigations of the Bureau of Mines on coke in the blast-furnace, penetration and combustibility of coke, size of combustion zone and size of coke, carbon gasified above the tuyeres, fast-burning coke, size and strength of coke and resistance of the charge to flow of gas, are also discussed. Failure to define the properties of coke clearly is partly responsible for retarding progress in correlating coke properties and furnace practice. If combustibility, a property of the fuel, is distinguished from rate of combustion, a factor controlled by rate of air supply, the term is of value in correlating coke quality and furnace practice. Highly combustible coke will not burn faster before the tuyeres than less combustible coke, but it will burn in a smaller volume. The size of the combustion zone, controlled largely by the size of the coke, affects the working of the furnace with respect to the furnace walls.

A. C. Fieldner and J. D. Davis, *Reactivity, a Factor in Selecting Foundry Coke* (Fuels and Furnaces, 1927, vol. 5, Sept., pp. 1181-1188). The authors discuss the physical and chemical characteristics desirable in foundry coke, and describe methods in use by the Bureau of Mines for the determination of combustibility and reactivity of coke. Highly reactive coke, such as low-temperature coke, is unsuitable for foundry

use because it will produce too much carbon monoxide, which results in loss of heat for melting pig iron. The less reactive coke, as shown by the tube-furnace test with carbon dioxide, should be the best coke for cupola use, provided other factors of size and resistance to breakage and abrasion are equal.

G. A. Brender à Brandis and J. W. Le Nobel, *Comparative Researches on the Reactivity of Coke* (Het Gas, 1927, vol. 47, Jan. 15, pp. 37-47). As the reactivity of coke plays such an essential part in its many applications, the authors make a critical survey of the methods used for determining this quality. Instead of determining the temperature at which the reduction of carbonic acid commences, it would be preferable to study this reaction at one definite temperature. The kindling point in air, determined according to Bunte, does not always coincide with the true reactivity of the coke. In general, the reactivity to air and to carbonic acid appear to parallel one another. There is reason for attributing great importance to the catalytic action of the ashes on the reactivity of coke.

S. W. Parr and W. D. Staley, *The Reactivity of Coke* (Industrial and Engineering Chemistry, 1927, vol. 19, July, pp. 820-822). Ignition experiments on cokes from an Illinois coal are described. The coal was carbonised at temperatures ranging from 500° to 1000° C. and showed a progressive rise in ignition temperature from 144° to above 600°. The variation is explained by graphitisation, and it is concluded that for each increase in temperature carbon assumes a definite form which directly affects its reactivity.

The Reactivity of Coke (Fuel Economist, 1927, vol. 2: Apr., pp. 391-395; May, pp. 447-450; June, pp. 507-510; July, pp. 562-563; Aug., pp. 611-612). The information contained in these articles has been taken from the volume by R. Mezger and F. Pistor entitled "Die Reaktionsfähigkeit des Kokes, ihre Ursachen, alte und neue Wege zu ihrer Bestimmung."

T. F. E. Rhead and R. E. Jefferson, *Determination of Relative Ignitabilities and Combustibilities of Domestic Cokes. Tests on the Possibilities of a Brazier and Weighing Method* (Journal of the Society of Chemical Industry, 1927, vol. 46, pp. 166-172T). A method for determining the relative ignitabilities and combustibilities of domestic coke has been investigated. The results show the effects of grade of coke, size of fire, and grate area on the rate of combustion.

Testing and Combustibility of Coke (Mining and Metallurgy, Jan. 1927, pp. 13-15). Particulars are given of the discussion which took place at the Round Table Conference on the combustibility and testing of coke before the American Institute of Mining and Metallurgical Engineers.

W. Diamond, *The Combustibility of Coke* (Paper read before the Institute of British Foundrymen: Foundry Trade Journal, 1927, vol. 35, May 26, pp. 448-450). The factors influencing the combustibility of coke in cupolas are briefly discussed.

E. R. Thews, *Cupola Coke* (Iron and Steel Industry, 1927, vol. 1, Nov., pp. 41-42). Pouring temperatures, coke combustibility and porosity, ash content, effect of carbon content on the coke, and the desired physical properties of coke are discussed.

N. A. Ross, *Determination of the Porosity of Coke* (Gas World, Coking Section, 1927, vol. 87, Sept. 3, pp. 97-98).

R. P. Hudson, *Properties of Metallurgical Coke* (Blast-Furnace and Steel Plant, 1927, vol. 15, Nov., pp. 526-527). The properties and characteristics which coke should possess for its most efficient use in the blast-furnace are enumerated.

H. Krueger, *Lower Silesian Foundry Coke and its Properties* (Giesserei Zeitung, 1927, vol. 24, Sept., pp. 487-492). A report on the calorific value, combustibility, volatile matter, porosity, strength, ash content and composition, sulphur, moisture, size, and appearance of Silesian coke.

S. Qvarfort, *Properties and Uses of Coke* (Gas- und Wasserfach, 1927, vol. 70, pp. 646-651). A description of the chemical and physical properties which metallurgical coke should possess.

Low-Temperature Carbonisation.—R. A. Strong, *Low-Temperature Carbonisation of Bituminous Coals* (Canada, Department of Mines, Mines Branch : Investigations of Fuels and Fuel Testing, 1925, pp. 64-100). The results are presented of tests carried out on two Canadian coals and one American coal. In order to study the reactions taking place at different temperatures and under different conditions, a series of carbonisation tests on each coal was conducted at maximum temperatures of 400°, 500°, and 600° C., according to the regular laboratory method, and on one of the coals at several temperatures, first in the presence of steam, and then with recirculation of the uncondensed gases.

The Ravine Seam of the Lancashire Coalfield (Physical and Chemical Survey of the National Coal Resources, 1927, No. 9. London : H.M. Stationery Office : Iron and Coal Trades Review, 1927, vol. 115, Aug. 5, pp. 195-196). Particulars are given of the tests carried out at the Fuel Research Station on carbonisation, in continuous vertical retorts, of coal from the Ravine Seam. The analyses of the coal, coke, tar, and liquor, and the general effects of steam on the yields of products, are given. Details of tests carried out in a Lancashire boiler using Ravine coal and coke as fuel are included.

W. Runge, *Low-Temperature Distillation* (Paper read before the American Society of Mechanical Engineers, Apr. 4-6, 1927 : Mechanical Engineering, 1927, vol. 49, July, pp. 875-878). A general discussion dealing with three processes of low-temperature distillation (rotary kiln, concentric drum type of retort, and horizontal stationary type of retort), the calorific value of the semi-coke produced, and the price at which the coke should sell, including a conservative estimate of production costs and profit.

J. Roberts, *Low-Temperature Carbonisation. Systems Employing Preheating* (Fuel Economist, 1927, vol. 2, May, pp. 450-453). Preheating systems may be grouped into three classes: (1) Preheating and oxidising at temperatures below $300^{\circ}\text{C}.$; (2) preheating at temperatures below $300^{\circ}\text{C}.$ without oxidising; and (3) fractional coking or partial distillation at temperatures ranging from 300° to $450^{\circ}\text{C}.$ The three classes are outlined.

R. M. Crawford, *Low-Temperature Carbonisation of Coal* (Paper read before Prime Movers Committee, N.E.L.A., Columbus, Feb. 16, 1927: Blast-Furnace and Steel Plant, 1927, vol. 15, May, pp. 229-233). Various systems for carrying out the process of low-temperature carbonisation are described, and the features which distinguish them are pointed out. Attention is drawn to the economies which may be effected by carbonisation at low temperatures.

D. Brownlie, *Low-Temperature Carbonisation of Bituminous Coal* (Engineering, 1927, vol. 124, July 8, pp. 36-38). The author gives a list of fifty low-temperature processes, which, in his opinion, are the most promising methods for treating bituminous coal, and describes very briefly their operation.

The Illingworth Carbonisation Plant (Colliery Engineering, 1927, vol. 4, Sept., pp. 357-361). A detailed illustrated account is given of the Illingworth carbonisation plant, which is in successful commercial operation at Treforest, Glamorganshire. The capital cost of the plant is stated to be 15s. per ton capacity. Operating costs, including power, labour, depreciation, interest on capital, sundry stores, and overhead charges, are 5s. 6d. per ton.

C. H. Lander, *Low-Temperature Carbonisation* (Fuel Economy Review, 1927, vol. 6, pp. 16-18). A brief review of recent developments in low-temperature carbonisation.

The Turner Low-Temperature Carbonisation Plant (Engineering, 1927, vol. 123, May 6, pp. 559-561). See Journ. I. and S.I., 1927, No. I. p. 816.

C. D'Huart, *The Low-Temperature Distillation of Coal* (Chaleur et Industrie, 1927, vol. 8, Sept., pp. 512-514). The author describes the Kohlenscheidungs-gesellschaft-Stinnes process.

V. Neveux, *The Distillation of Bituminous Schists* (Génie Civil, 1927, vol. 90, June 25, pp. 617-620). The Bartolomi and Pieters retorts are described.

V. Neveux, *New Process for the Low-Temperature Distillation of Coals* (Génie Civil, 1927, vol. 91, Oct. 1, pp. 325-327). The advantages and disadvantages of low-, medium-, and high-temperature carbonisation of coals are discussed, and the claims made for the Pieters process are enumerated.

H. Besson, *The Low-Temperature Distillation of Coal* (Génie Civil, 1927, vol. 91, Sept. 17, pp. 265-271). A description of the Cantieny retort installed at Karnap at the Stinnes Mines, near Essen.

G. A. Orrok, *The Economics of Coal Carbonisation in the United*

States (Paper read before the American Society of Mechanical Engineers, May 23-26, 1927 : *Mechanical Engineering*, 1927, vol. 49, Oct., pp. 1055-1059).

A. D. Little, *Impending Changes in our Use of Fuels* (Paper read before the Engineering Foundation, New York City, May 19, 1927 : *Forging, Stamping, Heat Treating*, 1927, vol. 13, July, pp. 280-284 ; *Mechanical Engineering*, 1927, vol. 49, Sept., pp. 952-954). A general review of accomplishments towards the conservation of coal resources. Brief descriptions of a number of low-temperature carbonisation processes are given.

By-Product Recovery.—*Works of the Yorkshire Coking and Chemical Co., Ltd.* (*Iron and Coal Trades Review*, 1927, vol. 115, Oct. 7, pp. 523-527). An illustrated account is given of the layout and equipment of this plant, which consists of 140 Koppers regenerative ovens with a by-product plant for the recovery of sulphate of ammonia, crude benzol, and tar. Particulars are also included of the coal washery.

W. Glud and W. Klempt, *Recovery of Ammonium Thiocyanate in Coking* (*Zeitschrift für Angewandte Chemie*, 1927, vol. 40, pp. 659-660). Experiments on a large scale have been made for the removal of hydrocyanic acid from coke-oven gases by the thiocyanate process. The crude gases are passed through washers in which circulates an aqueous sulphur suspension. Two thousand to three thousand cubic metres of crude gas per hour were treated, and after twelve days the solution attained a strength of 20 per cent. by weight of ammonium thiocyanate, the efficiency of extraction of hydrocyanic acid being 98 per cent.

R. M. Crawford, *Elimination and Recovery of Phenols from Coke-Plant Ammonia Liquors* (*Industrial and Engineering Chemistry*, 1927, vol. 19, Sept., pp. 966-968). In previous articles the author described a method for eliminating phenols from ammonia still wastes by the continuous, counter-current extraction of the raw liquor with benzene, in a process wherein the phenols removed from the liquor are recovered as a saleable by-product in the form of crude tar acids. The purpose of the present article is to describe a further substantial improvement in the process wherein a less costly and more efficient solvent, readily available at any coke plant, can be utilised and additional saleable crude tar acids can be incidentally recovered. The use is made of neutral coal tar light oils as a solvent.

H. Nielson and S. Baker, *Lubricating Oils from Coals* (*Mechanical Engineering*, 1927, vol. 49, Oct., pp. 1109-1110). *The Production of Lubricating Oil from Coal* (*Engineering*, 1927, vol. 123, June 3, pp. 665-666). The article gives a description of the method of preparing lubricating oil worked out by Messrs. Sensible Heat Distillation, Ltd., with a report of the National Physical Laboratory on comparative tests of the "L. and N." lubricating oil against a straight mineral lubricating oil. The practicability of the production of lubricating oil from coal is said to be determined largely by the method of distillation adopted ;

the solution of the problem is within reach if the "internal heat application" method is used, and the oils must be removed from the retort before condensation of the high-boiling fractions can take place, in order to prevent re-evaporation and cracking.

IV.—LIQUID FUEL.

Oil Shale in Scotland.—R. G. Carruthers, W. Caldwell, E. M. Bailey, and H. R. J. Conacher, *The Oil Shales of the Lothians* (Geological Survey of Scotland, 1927: H.M. Stationery Office). The third edition of this Memoir contains a description of the geology of the oil shale fields of the Lothians and Fife, and a complete account of the methods employed in mining and retorting the shales and in refining the crude oil. A great deal of new material has been included in the revised memoir.

Canada.—W. A. Bell, *Oil and Gas in the Maritime Provinces* (Paper read before the Second Empire Mining and Metallurgical Congress, Canada, 1927). A résumé of the stratigraphy and geological history of the Atlantic Provinces, and a critical analysis of the more authentic oil seepages are given.

O. B. Hopkins, *Oil and Gas Developments in the Foot-Hills Belt of Alberta and British Columbia* (Paper read before the Second Empire Mining and Metallurgical Congress, Canada, 1927).

R. B. Harkness, *The Oil and Gas Fields of Ontario* (Paper read before the Second Empire Mining and Metallurgical Congress, Canada, 1927).

G. S. Hume, *Oil Prospects of British Columbia* (Paper read before the Second Empire Mining and Metallurgical Congress, Canada, 1927).

G. S. Hume, *Oil and Gas Prospects of the Great Plains of Western Canada* (Paper read before the Second Empire Mining and Metallurgical Congress, Canada, 1927).

Trinidad.—P. Munoz, *New Oil Fields in Trinidad* (Mining and Metallurgy, July 1927, pp. 311-314).

Auxiliary Sources of Liquid Fuel.—A. W. Nash, *Possible Auxiliary Sources of Liquid Fuels* (Paper read before the Second Empire Mining and Metallurgical Congress, Canada, 1927). The author reviews the various means of obtaining liquid fuel, and discusses their commercial value.

Oil Burners.—*A New System of Burning Oil Fuel* (Engineer, 1927, vol. 144, Sept. 2, p. 264). A new type of oil burner is described. It consists of an open cast-iron trough with hollow walls which serve as

air-heating spaces. The oil is delivered to the bottom of the trough through one or more inlet connections with approximately a $\frac{3}{16}$ -in. opening, terminating about $\frac{1}{2}$ in. above the bottom of the trough. There is also an overflow connection, which is lower. The air is admitted through two rows of staggered holes arranged in the sides of the trough at such an angle that the air jets pick up the gasified fuel. The air is supplied by a fan, and automatic controls are fitted to prevent flooding of the burners in the event of failure of the air supply. The burners described are fitted to a boiler.

V.—ARTIFICIAL GAS.

Gas-Producers and Producer Practice.—H. Barth, *Gas-Producer for the Gasification of Combustibles of High Value and of Medium Value, and of Waste* (Keramische Rundschau, 1926, vol. 34, July, pp. 494–497). The author has designed a gas-producer which, by suitable and easily made rearrangements of the grate, can be operated on all sorts of fuel, whether of high or low value. By means of a special arrangement dusty materials can also be utilised.

G. Neumann, *Practice and Directions for Gas-Producer Working (Air and Steam Supply)* (Archiv für das Eisenhüttenwesen, 1927, vol. 1, July, pp. 47–56; Aug., pp. 137–146). The cost of gas is increased by unsuitable methods and poor appliances for supplying the air to gas-producers. The peculiarities of running with centrifugal fans are described, questions of air speed in mains and the influence of varying the speed of the blower on power consumption are considered. Directions for calculating and constructing the air mains and blowers are given, and rules for control and automatic regulation of air pressure are proposed. Consideration is given to safety and anti-explosion devices and cost of steam supply. Air preheating and enrichment with oxygen are considered feasible for the gasification of lignites if it is proposed to distribute a rich gas to distant centres.

A. T. Grisenthwaite, *Producer-Gas* (Fuel Economy Review, 1927, vol. 6, pp. 26–29). Developments in the design and operation of gas-producers are briefly outlined.

G. W. Hewson, *The Application of Blast-Furnace Gas to Gas-Producer Practice* (Fuel Economist, 1927, vol. 2, May, pp. 443–444). The whole of the information contained in this article has been taken from that of McDermott (Blast-Furnace and Steel Plant, 1925, vol. 13, Sept., pp. 344–346; *abstract*, Journ. I. and S.I., 1926, No. I. p. 532).

Influence of the Ash Constituent in the Carbonisation and Gasification of Coal. Part III.—Gasification of Special Cokes (Institution of Gas Engineers, Gas Research Fellowship Report, 1927; Gas Journal,

1927, vol. 178, June 22, pp. 895-912; Gas World, 1927, vol. 86, June 25, pp. 680-681). The report is divided into three parts, dealing with the gasification of special cokes in steam, in carbon dioxide, and in oxygen, respectively.

T. Cerasoli, *Gasifying Fuels by Oxygen and Steam* (Gas- und Wasserfach, 1927, vol. 70, pp. 508-510). The gasification of carbon by a mixture of oxygen and steam has been studied and the oxygen requirement, equilibrium temperature, quantity, and composition of the resulting gas, have been calculated for different values of the steam consumption per kg. of carbon. The gas yield per kg. of coal is increased by about 20 per cent. when using oxygen.

R. Nitzschmann, *Flame Temperature of Producer-Gas, using Pre-heated Air and Gas* (Chemiker Zeitung, 1927, vol. 51, pp. 197-198). The author gives detailed formulæ and a number of curves for the determination of the flame temperatures of producer-gas burned with O_2 - N_2 mixtures, with air ranging up to 100 per cent. of O_2 for various conditions of preheating.

R. de Kergaradec, *The Mechanical Cleaning of Gases* (Chaleur et Industrie, 1927, vol. 8, Sept., pp. 505-511). The author discusses the principles underlying the use of mechanical gas cleaners; he deals particularly with the waste gases resulting from the combustion of pulverised fuels.

Gas Power Plant.—*Utilisation of Coke-Oven Gas* (Colliery Guardian, 1927, vol. 135, Oct. 7, pp. 524-525). Particulars are given of a gas-engine installation utilising surplus coke-oven gas. At the Rockingham coke-ovens the surplus gas is used for the production of electricity. The gas after scrubbing is led into a 110,000 cu. ft. gas-holder; thence it is led through oxide purification beds. The first gas-engine set was installed twelve years ago, and is of the eight-cylinder vertical tandem type of 600 B.H.P. operated on the four-stroke cycle system. The engine is direct coupled to a generator, with an output of 450 kw. at 3300 v. The coke-oven gas is mixed with inert exhaust gas to lower the calorific value and to prevent pre-ignition. Another set has been recently installed consisting of a 600 B.H.P. six-cylinder engine of the vertical type, which also operates on the four-stroke cycle system. Test figures obtained on this set show that the over-all efficiency taken from the calorific value of the gas to the switchboard is 29 per cent.

P. H. Borchardt, *Treatment of Coke-Oven Gases in Relation to Distance Distribution* (Paper read before the German Gas Association, June 1927: abstract, Gas World, 1927, vol. 87, Aug. 6, pp. 123-124).

T. S. Ess and G. Fox, *The Power Plant at Betty Furnace* (Frey Design, Oct. 1927, pp. 1-10). The outstanding features in the design of the electric power plant at the Betty furnace of the Central Alloy Steel Corporation are described and the reasons leading to their adoption are discussed. The present electric power development involves a single 10,000 kw. turbine generator, which is sufficient to utilise all the

blast-furnace gas at periods of maximum availability. At periods of reduced gas supply the deficiency is made up from coke breeze and pulverised fuel. The power plant also provides air for blowing the blast-furnace, and steam for both the blast-furnace and coke-ovens. The boiler plant includes six boilers, each having 8900 sq. ft. heating surface. The turbo-blowers have a maximum capacity of 60,000 cu. ft. per minute and a maximum pressure rating of 32.7 lb. gauge. The single turbine generator is a 10,000 kw., 1800 r.p.m., 11,000 v., 60-cycle machine.

J. D. Donovan, *A Year's Operation of Power Plant at Betty Furnace* (Freyn Design, Oct. 1927, pp. 19-20).

H. W. Neblett, *New Power Plant at Steel Works* (Blast-Furnace and Steel Plant, 1927, vol. 15, May, pp. 234-241). The article gives a very complete description of the power-generating plant being installed at the Minnequa Steelworks at Pueblo, Colorado, of the Colorado Fuel and Iron Co. When completed the plant will have displaced 118 boilers. Two main turbo-generator units are installed in the power-house, and a third is under construction; these units are 10,000 kw. (12,500 kva.), 6600 v., 3-phase, 60-cycle machines. Four turbo-blowers are installed for supplying air to the blast-furnaces: they are rated at 55,000 cu. ft. of air per min. at 25 lb. pressure for the altitude at which they are situated, namely, 4800 ft., and this corresponds to a rating of 60,000 cu. ft. at sea-level. As the annual rainfall in the district averages 12 in. or less, the provision of the 32 million gallons of water required daily by the steelworks presented a serious problem; it has been solved by the provision of storage reservoirs in the mountains which are mainly fed from snowbanks. In the boiler-house are seven 1200 H.P. Stirling type water-tube boilers, without economisers, designed to operate at 330 lb. steam pressure and 200° F. superheat. The fuels for firing the boilers are blast-furnace gas and powdered coal, the central pulverising plant for the provision of the latter having a capacity of 18 tons per hour. The blast-furnace gas is cleaned by the Cottrell electric precipitation process; the dust from the gas, on account of its high iron content (42 per cent. iron), is sintered and recharged into the blast-furnace, and at the same time the sensible heat of the gas is not lost.

R. D. Abbiss, *Recent Boiler Plant Installation at Edgar Thomson Works, Carnegie Steel Co.* (Iron and Steel Engineer, 1927, vol. 4, June, pp. 285-296). A detailed illustrated description is given of the new boiler plant at these works.

H. Wolf, *Gas-Engine or Steam Turbine* (Archiv für das Eisenhüttenwesen, 1927, vol. 1, Oct., pp. 285-296). Steam-power generation has made great progress in recent years, due to the greater output and efficiency (85 per cent.) of boilers and improved treatment of feed water. The turbine has been improved by utilising a greater heat drop, consequent on higher pressures and temperatures, heat regeneration from exhaust, improvement in thermodynamic efficiency, and

construction of large units. These advantages are exemplified, and "bleeding" is also discussed. It was stated, based on Münzinger, that at 100 atmospheres, 400°C ., and with bleeding and reheating, 2643 kg.-cal. per kw.-hr. are attainable against the 2650 of the Diesel engine. Actual results from up-to-date German stations using steam at 30 atmospheres and 400°C . vary from 3520 to 3920. The steam plant has the advantages of ability to deal with overload, and requires a lower capital outlay than a gas-engine plant. In comparisons instituted between gas-fired and pulverised coal-fired stations, 1.06–0.83 pfg. per kw.-hr. was allowed for clean furnace gas, and 0.77 to 0.61 pfg. for pulverised coal firing. The cost of the plant varies with the arrangements, and figures of 281 to 170 marks per installed kw. are given for stations with gas firing, and 308 to 199 for pulverised firing.

Fr. Bartscherer, *Gas-Engine or Steam-Turbine* (Archiv für das Eisenhüttenwesen, 1927, vol. 1, Oct., pp. 297–312). The conditions which determine the economy of a heat engine, such as heat consumption, running costs, prime costs, are critically examined, with reference to the power and heat economy of iron and steel works. It is shown that it cannot be definitely and generally laid down which prime mover is the more economical, as the conditions in various works are so different. Under some conditions the gas-engine would be too expensive, but for most cases it is still the more economical. Its advantage over the steam turbine is disappearing, especially taking account of depreciation, and if the turbine can really operate continuously on a heat consumption of 4500 kg.-cal. (based on coal). The recent improvements of the gas-engine, including scavenging and boilers heated by exhaust gases, are fully discussed. The heat consumption for the ordinary engine is given as 4000 kg.-cal. per kw.-hr., or an over-all efficiency of 21.5 per cent. If exhaust heat boilers are used and steam is transformed to power this efficiency is increased to 28.62 per cent., and with utilisation of the heat of the cooling water this is further raised to 32.2 per cent., or a heat consumption of 2790 kg.-cal.

H. Bansen, *Calculation of Fall in Pressure in Gas Mains and Bricked Flues* (Archiv für das Eisenhüttenwesen, 1927, vol. 1, Sept., pp. 187–192). The formula, due to Brabbée and Fritsche, giving the frictional resistance of a tube, was simplified by introducing simple and quadratic functions instead of the usual exponentials. It is shown that these simplifications hold for the gas mixtures and pressures usually encountered. Separate resistances, such as bends, are discussed and data given for their calculation, including considerations on checker work.

A. Fischer, *Calculation of the Pipes for a Supply System for Heating by Blast-Furnace Gases* (Revue Technique Luxembourgeoise, 1927, vol. 19, May–June, pp. 62–64). Seven diagrams, based on Monnier's formula, are given for evaluating the size of pipes required according to the volume of gas and the length of conduit to be considered.

VI.—COAL WASHING AND HANDLING.

Coal Cleaning and Screening.—W. R. Chapman and R. A. Mott, *The Cleaning of Coal* (Fuel, 1927, vol. 6, May, pp. 197–212; June, pp. 257–266; July, pp. 293–311; Aug., pp. 340–358; Sept., pp. 388–397). The authors continue their series of articles on the washing of coal. Article XIV. deals with dry-cleaning processes, and describes the Wye separator, not yet in commercial use in this country, the pneumatic table installed at Wardley, County Durham, the Arms Air Concentrator, two of which are in use at Ashington Colliery, Northumberland, and the Peale-Davis table, which treats unsized coal. Apparatus has also been devised to separate coal from dirt by virtue of differences in friction—Pardee's spiral separator works on this principle—and much more recently the Barrisford process has been introduced. The Dry Coal Cleaning Company has also lately introduced a new process at one or two collieries. Article XV. describes processes depending on the use of a medium of high density, such as sand. Of these the Chance and Conklin processes are examples. In Article XVI. the froth flotation processes are illustrated and described. Their chief interest is that they provide a method of cleaning the smallest sizes of coal, but they are not so suitable for coal as for concentration of ores on account of the difficulty and expense of dewatering the washed coal. Article XVII. discusses the drying of washed coal, and describes various types of centrifuges for the purpose. In Article XVIII. the methods of judging the efficiency of washeries and the systems of sampling are considered.

W. R. Chapman and R. V. Wheeler, *Comparison of Processes for the Cleaning of Coal* (Paper read before the Coal-Cleaning Conference, July 1927: Colliery Guardian, 1927, vol. 134, July 8, pp. 83–84; July 15, pp. 146–148). From the comparisons drawn between the different processes in different circumstances it is clear that there can be no one coal-cleaning process that is universally the best, and no process yet devised can be regarded as the most suitable for cleaning all coals under all conditions. Apart from considerations regarding the character of the coal to be treated, the choice of a cleaning process will depend upon such matters as: the desirability of a wet or a dry process; the ultimate use to which the coal is to be put; and the space, building, and accessory plant already available. The choice will, however, depend primarily on the nature of the coal. In this respect guidance is given by (a) a series of screening analyses of the raw coal; and (b) a series of float and sink tests on sized samples of the raw coal in a number of liquids of different specific gravities.

Cleaning Small Coal by the Hydrotator Process (Colliery Engineering, 1927, vol. 4, May, pp. 204–205). The applications of the hydrotator to coal cleaning are, cleaning anthracite fines from $\frac{3}{8}$ in. down to dust; cleaning coal too small for treatment by other established processes;

removing coal from the sand used in the Chance sand-flotation process ; cleaning bituminous coal from $\frac{3}{8}$ in. down to dust ; and for carrying out coal cleaning according to the froth-flotation process. The standard form of hydrotator is shown, and the method of operation and the results obtained are given.

W. R. Chapman, *The Rhéolaveur Washing Plant at Barnsley Main Colliery* (Colliery Guardian, 1927, vol. 135, Sept. 2, pp. 29-33). A detailed description is given of this washery, together with particulars of operating results.

C. Berthelot, *Recent Progress in the Technique of Coal Washing* (Revue de l'Industrie Minérale, 1927, No. 159, Aug. 1, pp. 313-326). The author describes the aim and characteristics of a coal washery ; he gives classification curves of coals, and discusses the suitability of a coal for washing. He reviews the physical laws governing the washing of coal, and refers to the classification of coals by size before washing ; he also recounts the arguments for and against the removal of the dust. He indicates briefly the conditions concerning the washing of coal by three general methods.

J. L. Thomson and C. N. Kemp, *The Float and Sink Testing of Small Coal ; a New Laboratory Unit* (Journal of the Society of Chemical Industry, 1927, vol. 46, June 3, pp. 206-209T). The float and sink test, otherwise known as fractional analysis or heavy solution analysis, is the outcome of laboratory experience in the separation of samples of coal into series of fractions of increasing density. A simple apparatus for the purpose of the test has been devised and is described and illustrated.

G. Dörflinger, *Recognition and Estimation of Structural Constituents of Coal by Means of the Float-and-Sink Test* (Archiv für das Eisenhüttenwesen, 1927, vol. 1, July, pp. 3-9). In view of the great differences which may exist between coals despite identical elementary analysis, it has been suggested that a flotation process be employed to test the uniformity or otherwise of coals supplied to a coke-oven plant. By floating the coals at the same temperature in liquids of graded sp. gr. a general idea of their constitution and "under-value" figure is obtained. The relation of the figure to the quality of the coal can be proved by coking tests. The mixing of various varieties of coal can only be made according to special rules if it is desired to obtain a uniform coke. Expensive coking coals should only be added if the value of the mixture demands it. If two coals are to be mixed, one of which is uniformly good, then there is the possibility that a uniform product may be obtained.

O. Schäfer, *The Economic Importance of Drying Coking Coal* (Glückauf, 1927, vol. 63, June 11, pp. 857-867). A study of the economic aspect of drying coking coal is summed up as follows : The economy of a coal washery is dependent not only on the amount of throughput, but on the ultimate water content of the coking coal. The maximum throughput is reached only when all particles, right down to

0-0.2 mm., are washed. The water content of the coal after drying is dependent on the proportion of fine grain of 0-0.1 mm. By drawing off the finest grains before washing and adding them afterwards, the moisture content and also the throughput are considerably reduced. If on obtaining the maximum throughput, say by the use of the flotation process for the finest dust, the moisture at the end is too high, the drying of the total coal in drying drums down to 6 per cent. water is recommended.

Draper Washery at Coppull Colliery (Iron and Coal Trades Review, 1927, vol. 114, June 24, pp. 991-992). The plant at Coppull Colliery consists of twenty-one washing units, which are arranged in three batteries of seven each, the total capacity of the plant being 35 tons per hour when dealing with slack. The equipment of the plant is described and illustrated.

Broadway Washing Table at Garswood Hall Colliery (Iron and Coal Trades Review, 1927, vol. 115, Aug. 5, p. 199). Brief particulars are given of the arrangement of the Broadway washing table conveyor and driving gear for the treatment of fine coal. The table in operation at Garswood Hall Colliery is dealing with fines all below $\frac{3}{8}$ in.

W. Guider, *Froth Flotation as Applied to a Baum Washer* (Paper read before the Coal Cleaning Conference, July 1927 : Colliery Guardian, 1927, vol. 134, July 15, pp. 145-146).

F. R. Wadleigh, *Bituminous Coal Preparation in the Eastern Fields* (Paper read before the American Society of Mechanical Engineers, Feb. 11, 1927 : Mechanical Engineering, 1927, vol. 49, June, pp. 650-654). The author discusses the important results obtained by coal preparation. The nature and source of the ash, methods of preparation, mechanical cleaning, and the various types of cleaning equipment are dealt with, and the general conditions for preparation in the various large producing districts are reviewed.

C. W. H. Holmes, *Notes on Cleaning of Coal, with Special Reference to Pneumatic Separation* (Journal of the Society of Chemical Industry, 1927, vol. 46, July 8, pp. 270-279T). The author discusses the development of pneumatic separation as opposed to hydraulic classification, giving consideration to the laws governing the separation of particles by virtue of the difference in their densities. The dry cleaning of coal by pneumatic separation is discussed in relation to the coking industries, and some notes are appended describing recent investigations on pneumatic separation carried out by the Birtley Iron Company.

K. C. Appleyard, *Sutton-Steele-and-Steele Process of Cleaning Dry Coal* (Paper read before the Institute of Mining Engineers : Iron and Coal Trades Review, 1927, vol. 115, July 1, pp. 12-13 ; July 8, pp. 50-51). The process, which is of the pneumatic separator type, is described, and the results of tests are tabulated. The question of sizing in dry-cleaning processes, the effect of moisture, reduction in ash content, and the dust problem are discussed. The advantages of dry cleaning are also pointed out.

I. Katayama, *Alteration of Young Coals by Drying at 105°* (Journal of the Society of Chemical Industry, Japan, 1926, vol. 29, Aug., pp. 116B–117B). The author describes experiments and their results, carried out by heating to 105° C. under various conditions, young coals from Corea, which belong to an old type of tertiary lignite. He demonstrates that an alteration in the coal does take place at this temperature, and suggests that the desiccation of samples of coal before carrying out experiments may result in conclusions which bear no relationship to those which would be drawn from tests carried out on the samples without preliminary drying.

New Screening Plant at Coventry Colliery (Iron and Coal Trades Review, 1927, vol. 114, June 17, pp. 957–959). The arrangement of the screening plant at the Coventry Colliery of the Warwickshire Coal Co. is described and illustrated. The new screens recently put into operation are capable of dealing with 1200 tons in 17 hrs., handling at the same time 350 tons of small coal from the old screens. A provision has been made for addition to the plant which, when completed, will be capable of dealing with 2000 tons per shift in addition to handling the small coal.

Coal Briquetting.—W. C. Moore and H. A. Myers, *Briquette Binders containing Residues from Alcohol Manufacture* (Industrial and Engineering Chemistry, 1927, vol. 19, Jan., pp. 147–149). Molasses residue from alcohol manufacture will form emulsions with petroleum-pitch asphalt which may be employed as binders in the manufacture of briquettes from anthracite culm. The addition of sulphur to the residue renders the binder less liable to leeching when immersed in water. A suitable composition of the binder is stated.

Ch. Berthelot, *The Installation of Semi-Carbonisation and of Agglomeration of the Lignites from the Coal Mines in the Basin of the Tave (Gard)* (Génie Civil, 1927, vol. 90, Feb. 12, pp. 168–172). The author describes the process and plant for dealing with the lignites mined near Bagnols in the department of Gard, France.

Storage of Coal.—Neumann, *New Researches on the Storage of Coal* (Wärme, 1926, vol. 49, Sept., pp. 642–644). The author has studied the behaviour of coals during storage. He finds that anthracite oxidises but little; in the case of bituminous coals, contact with dust, the formation of chimneys in the heaps, and the raising of the temperature towards 75° C. should be avoided; the heaps should not exceed 3 m. to 4·5 m. high; the coking power of coking coals is lowered; and the state of subdivision and the sulphur contents of the coals have an important effect.

PRODUCTION OF IRON.

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I.—MANUFACTURE OF PIG IRON.

Blast-Furnace Construction and Equipment.—A. Wagener, *Present State of the Blast-Furnaces in the Mineral Basin of Lorraine-Luxemburg* (Revue Technique Luxembourgeoise, 1927, vol. 19, June, Special Number, pp. 15-27). The author describes the present state of development of blast-furnaces in those regions where minette ore is smelted, and compares the advances and improvements with those made in Germany and in the United States. A large number of diagrams showing the progressive changes in blast-furnace lines in the States, in Germany, and in the minette ore basin are reproduced.

J. P. Dovel, *Improved Furnace on Southern Ores* (Iron Age, 1927, vol. 120, Sept. 22, pp. 782-784). The author describes the design adopted for the blast-furnaces of the Sloss-Sheffield Steel and Iron Co., Birmingham, Alabama. He discusses briefly each separate feature, and points out its advantage. It is claimed that the use of water cooling and the introduction of steeper inwalls permit more uniform distribution of the stock and result in increased production with lower coke consumption. It is believed that the improvements in practice are due to a relatively larger area in the upper part of the furnace, and to the distribution of the stock so as to place a sufficient amount of coarse material along the walls as well as in the centre of the shaft, thus causing the gases to flow upward uniformly through the whole mass and maintain a uniform temperature and flow throughout the furnace.

Wheeling Steel Corporation's New Furnace (Blast-Furnace and Steel Plant, 1927, vol. 15, Sept., pp. 444-445). A new blast-furnace is described. The bells are operated by electric hoists. The gas-washer is subdivided into six compartments, each being a complete washer in itself.

W. S. Orr, *From Wheat Field to Blast-Furnace Plant* (Freyn Design, Feb. 1927, pp. 1-6). An illustrated account is given of the new blast-furnace plant of the Central Alloy Steel Corporation.

W. R. Phibbs, *Making Iron with Utah Ore and Coal* (Freyn Design, Apr. 1926, pp. 1-2). A brief account is given of the blast-furnace plant of the Columbia Steel Corporation, Ironton, Utah, together with particulars of the raw materials used.

Derclaye, *Calculation of the Pressure Losses in Blast-Furnace Air Mains* (Revue de Métallurgie, Mémoires, 1927, vol. 24, May, pp. 237-254; June, pp. 317-330). Starting from first principles, the author shows how to calculate the most suitable sizes of pipe for the various mains and piping bringing air to the blast-furnace, and the losses of pressure which may be expected to occur.

R. Krüger, *Efficient Lighting in Iron and Steelworks* (Archiv für das Eisenhüttenwesen, 1927, vol. 1, July, pp. 69-76; Stahl und Eisen, 1927, vol. 47, Aug. 4, pp. 1287-1290). Various types of illumination are described, and views on requisite intensity and uniformity are presented. Examples are given of correct and incorrect practice, and the advantages of the former in increased production and prevention of accidents are noted.

Blast-Furnace Practice.—E. C. Evans, *Fuel Requirements in Iron and Steel Production* (Fuel Economy Review, 1927, vol. 6, pp. 39-43). The coke consumption and burden in average blast-furnace practice in this country and abroad are shown as follows:

	Ore and Limestone. Cwt. per ton of pig.	Coke. Cwt. per ton of pig.
U.S.A.	46·8	19·08
Canada	47·8	19·8
Belgium	56·0	21·2
Great Britain	58·8	26·6

The high fuel consumption in British furnaces is partly accounted for by difference in ores and coke quality, but a study of available records indicates that the following factors have their influence:

(1) Larger average size, and (2) faster driving of Continental and American furnaces as compared with British.

The influence of these two factors is discussed, and an analysis is given of some typical British, German, and American furnace practice. Calculations are presented of the fuel requirements of open-hearth and basic Bessemer plants.

J. E. Lose, *The Operation of Large Hearth Furnaces, Using Coke made from 100 per cent. High Volatile Coal* (Paper read before the American Iron and Steel Institute, May 1927). One of the most prominent factors in the increase of blast-furnace outputs during the past few years has been the installation of large hearth furnaces. This type of furnace has proved its ability to make greater tonnages of iron of equal or better quality with less coke than is possible with smaller hearth furnaces. Another factor of equal effect upon the tonnage

increase has been the tendency to drive the furnace to the upper limit of the blast capacity. Credit for the development of the large hearth furnace rests with the Edgar Thomson plant of the Carnegie Steel Co., and with the Chicago plant of the Illinois Steel Co. The author reviews the history of the development of these furnaces, and discusses their operation, including an analysis of the operating difficulties and the steps taken to overcome them. A table shows the average records of the Carrie large hearth furnaces over the entire period of their operation, and in addition gives the individual records of their highest average production for a period of one month. These productions are comparable with furnaces of equal size operating on soft ores and using coke made from 100 per cent. high volatile coals. They are, however, somewhat less than that of furnaces using the same ores, but using coke made from a mixture of high and low volatile coals. The coke rate and blast temperature of the Carrie furnaces are discussed. The flue-dust production at these furnaces is high, the amount produced ranging about 400 lb. per ton. Flue-dust has been used in varying amounts throughout the operation of these furnaces, and they are now using about 50 per cent. of the dust produced. It is found, however, that attempts to use higher quantities have resulted in more than proportional increase in flue-dust produced. The downward movement of the charge in the furnaces is discussed in full.

S. P. Kinney, P. H. Royster, and T. L. Joseph, *Iron Blast-Furnace Reactions* (United States Bureau of Mines, 1927, Technical Paper 391). The authors give the results of a detailed study of the reduction of iron oxides in a 300-ton blast-furnace. The furnace, method, and apparatus used in collecting gas samples, and procedure of tests, are described. Samples of gas taken from various planes lying between the tuyere level and the stock line show that certain parts of the furnace do more work than others because the stock moves unevenly. Combustion of coke in the hearth is taking place in a comparatively restricted zone at the nose of each tuyere. Oxygen of the blast is consumed 30 in. in a horizontal direction and 27 in. in a vertical direction from the centre of the nose of each tuyere. The CO_2 is reduced at a horizontal distance of 40 in., and probably at a like vertical distance. The extent of these combustion zones controls the movement of the stock in the upper part of the furnace. It has been suggested that more uniform movement might be obtained by rearrangement of these zones in an elliptical or oval hearth, not wider than twice the length of the zone of combustion. By doing so the average temperature of the hearth would be higher than in present furnaces, and combustion would proceed uniformly throughout the hearth area; therefore stock movement would be uniform in the stack.

R. Franchot, *The Theory of the Blast-Furnace* (Paper read before the American Iron and Steel Institute, May 1927). The author discusses (1) the blast-furnace as a gas producer; and (2) the disposition of hearth heat, two theories generally advanced to account for the

low efficiency of the blast-furnace as an iron producer. According to the author, the marked lack of uniformity in furnace action is at least partially explained on the basis of variation in the extent of nitrogen fixation due to variations in temperature, basicity, and alkali accumulation. Perhaps not the least impressive feature of the nitrogen theory is its serviceability toward explaining certain facts that appear otherwise inexplicable.

R. Franchot, *The Use of the Blast-Furnace as a Gas-Producer* (Proceedings of the International Conference on Bituminous Coal, 1926, p. 544: Fuels and Furnaces, 1927, vol. 5, Nov., pp. 1451-1454, 1476). In blast-furnace practice there is apparently a trend toward making gas production the primary function, with pig iron the by-product, and under ordinary conditions the production of more or better gas entails increased coke consumption with decreased iron output. A scientific study of the formation in the furnace of CO and hydrogen seems to indicate that it will be practicable to increase both iron and gas production as well as raise the calorific value of the gas, and decrease the coke consumption. The author discusses the generation of excess gas in the blast-furnace.

E. Bertram, *The Blowing-In of Blast-Furnace Dust and Powdered Fuel into the Blast-Furnace Bosh* (Archiv für das Eisenhüttenwesen, 1927, vol. 1, July, pp. 9-32). Trials in the blowing of flue dust and powdered coal and coke into the melting zone of a blast-furnace at the Halbergerhütte are described. With the low blast-pressure employed no difficulties were encountered. An alteration in chemical and physical properties is observable, but the iron produced is of the kind used for direct castings, and is not of finished foundry grade. The process is economical only when working the furnace for gas or when much cold blast is used in compensation. In any case it is less economical than briquetting the flue-dust, and it still remains to prove how it compares with sintering. The blowing-in of powdered fuel has not proved economical, but the possibilities of success are not yet exhausted.

F. Wüst, *A Contribution to the Theory of the Blast-Furnace Process* (Paper read before the Iron and Steel Institute, Sept. 1927: this Journal, p. 65).

C. S. Gill, *The Effect of Varying Ash in the Coke on Blast-Furnace Working* (Paper read before the Iron and Steel Institute, Sept. 1927: this Journal, p. 91).

K. Mühlbradt, *Calculations of the Temperature of Combustion in Shaft Furnaces* (Stahl und Eisen, 1927, vol. 47, Oct. 27, pp. 1813-1816). It is shown that the general method of calculating the primary temperatures in shaft furnaces, which is founded on the conditions of combustion and excess air, is wrongly based on data taken from gas-firing practice in which only gaseous phases react, whereas, in shaft furnaces, a reaction between heterogeneous phases occurs. Basing calculations on the process of combustion in a gas-producer, a scheme was evolved which takes into account the influences affecting the temperature in a

shaft furnace and renders possible the application of a thermodynamic theory.

G. Bulle, *Valuation of the Charge, Pig Iron, and Running Conditions in Blast-Furnace Practice* (Archiv für das Eisenhüttenwesen, 1927, vol. 1, Sept., pp. 161-176). Calculations, based on metallurgical and thermal considerations, of the influence of various ore and coke qualities and working conditions on the heat requirements of the furnace and possible ore and coke prices were made. It was suggested that each works should calculate and tabulate the thermal and metallurgical values of alterations in the above variables and complete them by actual tests. A basis of exact economic valuation of ore should be provided by this means. It was also proposed that when a change in quality occurs the base price for ore should be the price per unit of metal, and for coke per unit of useful carbon, determined analytically after deduction of that necessary to neutralise the effect of such impurities as ash, sulphur, and possibly water.

H. Bansen, *An Estimate of the Material and Heat Balances of the Blast-Furnace, Based on the Gas Analysis and Air Volume* (Archiv für das Eisenhüttenwesen, 1927, vol. 1, Oct., pp. 245-266). It is shown that alterations in the internal reactions of the furnace, such as separation of carbon, increased direct or indirect reduction, increased decomposition of water, and evolution of carbonic acid from the burden, are manifested in the waste gas analysis. Calculations are then made showing the influence on the coke consumption of essential running factors, such as gas composition, gas temperature, blast temperature, and quantity of slag. An inquiry into running irregularities led to a determination of the order of the effect of various influences. The present means for remedying heat shortage are inadequate, and the blowing-in of pulverised carbon above the tuyeres is suggested. It was deduced that a more complete and continuous check on the gas analysis is desirable.

P. Reichardt, *A New Heat Diagram for the Blast-Furnace* (Archiv für das Eisenhüttenwesen, 1927, vol. 1, Aug., pp. 77-103). The distribution and consumption of the heat provided by the fuel is given in heat units in the usual heat balance, but no reference is made to temperature. A diagram is shown in which the heat requirements of the various temperature zones are compared with the heat available in them. It appears from the diagrams given for furnaces in different countries and making various irons, that only in the upper region of the blast-furnace is there a great amount of surplus heat, while up to 900° the heat in other regions of the furnace is fully utilised. Conclusions are drawn as to heat consumption for decomposing limestone and melting scrap; further, the influence of the blast temperature is fully considered. The cause of the injurious effect of the carbon dust in the escaping gas current was tentatively explained. Finally, reasons are given as to why too much cannot be expected from the use of enriched air blast in place of hot blast, both from economic and

technical considerations ; but simultaneous injection of coal-dust and oxygen appears more promising.

What Goes on in the Blast-Furnace (Blast-Furnace and Steel Plant, 1927, vol. 15, Aug., pp. 367-371). A recapitulation of work carried out by Kinney, Barkley, and Joseph and Kinney, of the U.S. Bureau of Mines.

R. Moldenke, *Need for Research in Foundry Pig Iron* (American Institute of Mining and Metallurgical Engineers, 1927, Technical Publication No. 11 : *abstract*, Journ. I. and S.I., 1927, No. I. p. 840).

R. H. Sweetser, *Carbon in Pig Iron* (American Institute of Mining and Metallurgical Engineers, 1927, Technical Publication No. 11, pp. 28-35). Brief particulars are given of the results of tests carried out to determine the connection between the analysis of the gas at the tuyeres, the analysis of the slag and iron, and the temperature of the slag and iron, and further to determine if possible that part of the blast-furnace where the different metalloids enter the pig iron.

A. Michel, *Influence of the Blast-Furnace Working on the Total Carbon Content of Pig Iron* (Stahl und Eisen, 1927, vol. 47, Apr. 28, pp. 696-698 ; *abstracts*, Iron Age, 1927, vol. 120, Sept. 1, p. 535 ; Iron and Coal Trades Review, 1927, vol. 45, July 15, p. 88).

R. S. McCaffery, *The Cause of Variations in Pig Iron Qualities* (Paper read before the American Foundrymen's Association, June 1927). The author discusses the varying conditions in the blast-furnace which influence the quality of the pig iron. He points out that the properties of pig iron are not entirely due to its chemical composition, but that its compound composition may have profound influence.

E. Touceda, *A Pig Iron, Low in Carbon, is in Demand for Use in Various Industries* (American Institute of Mining and Metallurgical Engineers, 1927, Technical Publication No. 11, pp. 24-27). The author briefly discusses the importance of low-carbon pig iron to the malleable cast-iron founder.

D. McLain, *An Expression of Views on the Use of Iron Scrap in the Blast-Furnace* (Paper read before the American Foundrymen's Association, June 1927). The author does not believe that the mere fact that scrap is charged into the blast-furnace is responsible for the poor quality of foundry irons.

R. Moldenke, *The Evaluation of Foundry Pig Iron* (Paper read before the American Foundrymen's Association, June 1927). It is pointed out that the need for a standard method of evaluating the quality of pig iron in addition to chemical analysis is much greater at the present time, on account of the increased use of scrap in the blast-furnace.

I. Bohm, *A Study of the Blast-Furnace Process* (Jernkontorets Annaler, 1927, vol. 111, pp. 145-208). The author describes an exhaustive series of trials of the experimental blast-furnace at Hagfors, with different types of burden.

P. W. Uhlmann, *A New Blast-Furnace Process* (Blast-Furnace and Steel Plant, 1927, vol. 15, Apr., pp. 177-179; *abstract*, Journ. I. and S.I., 1927, No. I. p. 839).

C. H. Herty, jun., and J. M. Gaines, *Desulphurising Action of Manganese in Iron* (United States Bureau of Mines, 1927: Report of Investigations, No. 2817). The relation between the temperature and the solubility product, ($K = (\text{per cent. Mn}) (\text{per cent. S})$), for MnS in iron in contact, presumably, with solid MnS, was determined over the range 1100° to 1440° C. and 1.00 per cent. Mn to 1.75 per cent. Mn. The amount of dissolved MnS increases rapidly with the temperature, the change in the product for this range being from 0.030 to approximately 0.650. The composition of any liquid slag formed is pointed out as a probable factor in determining the magnitude of K . The effect of oxidation on desulphurisation, and the desulphurising action of manganese in the transfer ladle, are discussed. The higher temperatures prevailing within the blast-furnace and in the open-hearth make it probable, in view of the results presented in the report, that in these cases manganese cannot act directly as a desulphuriser; it may, and very probably does, assist indirectly other desulphurising reactions.

H. H. Meyer, *On the Reduction of Manganous Oxide, Silica, and Phosphoric Acid in the Blast-Furnace* (Mitteilungen aus dem Kaiser-Wilhelm-Institut für Eisenforschung, 1927, vol. 9, pp. 273-277). Experiments on the reduction of silica, basic slag, and manganous oxide in the presence of iron between 900° and 1200° C. by carbon, hydrogen, and carbon monoxide were made. The presence of iron causes the depression of the temperature of the commencement of reduction to the following values:

Manganous oxide, commencement of reduction	. 900°-950° C.
Phosphoric acid, commencement of reduction	. 1050° C.
Silica, commencement of reduction	. 1100° C.

With hydrogen the reduction of manganous oxide does not take place till 1200° C. is reached, but iron again depresses the temperature to 900° to 950° C. Equally, carbon monoxide does not reduce manganous oxide below 1200° C. The manganese, silicon, and phosphorus resulting from the reduction are protected from reoxidation by their diffusion into the iron, and in this manner their reduction at lower temperatures is demonstrated. Temper colours show that the concentration of silicon at the surface is much greater than is indicated by the analysis of a layer 1 mm. thick. In the blast-furnace, silicon, phosphorus, and manganese, like carbon, are taken up by cementation of the iron below the melting point.

A. Stansfield, *Smelting Titaniferous Ores of Iron* (Paper read before the Second Empire Mining and Metallurgical Congress, Canada, 1927). The paper contains a brief survey of the published information on the smelting of titaniferous iron ores, bringing out some points that have been overlooked by other writers, and showing how the conflicting

opinions of these writers can be reconciled in view of recent experiments. The paper also indicates the direction in which further information should be sought.

V. N. Lipine, *The Use of Titanium in the Production of Steel* (Bote der Metallindustrie, 1926, Mar.-Apr., pp. 5-17; Revue de Métallurgie, Extraits, 1927, vol. 24, Mar., pp. 136-137). The behaviour of titanium in the blast-furnace, the deoxidation of the steel bath with ferro-titanium, and the influence of titanium on the tensile properties of steel are discussed.

W. Macconnachie, *Alkalies in the Blast-Furnace* (Journal of the West of Scotland Iron and Steel Institute, Session 1926-1927, vol. 34, Part 6, pp. 79-84). The author discusses the action of alkalies in the blast-furnace, and gives the results of his investigations.

W. A. Forbes, *Technological Problems of the Steel Industry* (Paper read before the American Iron and Steel Institute, Oct. 1927). The purpose of this paper is to throw light on some of the major problems encountered in the manufacture of iron and steel. Numerous subjects are discussed, including mining and concentration of iron ore, coal and coke, blast-furnaces, utilisation of blast-furnace slag, open-hearth practice, technical problems affecting the quality of steel tubular products, and the annealing of sheet steel.

Iron Blast-Furnaces (Iron and Steel of Canada, 1927, vol. 10, May, pp. 140-145). A review of the uses to which oxygen is put in a blast-furnace plant—blowing-in, opening frozen tapholes, correcting irregularities in furnace working, and in welding structural parts for new structures or the repair of old parts.

E. Kieft, *Blast-Furnace Flue-Dust and Blast-Furnace Control* (Iron and Steel Engineer, 1927, vol. 4, July, pp. 345-348). The author has made a number of calculations pertaining to the cause of flue-dust production in the blast-furnace. The average properties of dry flue-dust produced by blast-furnaces operating on Mesaba ores are tabulated.

Dry-Blast.—E. H. Lewis, *The Use of Silica-Gel as a Medium for Drying Blast* (Paper read before the Iron and Steel Institute, Sept. 1927: this Journal, p. 43).

O. Ruff and P. Mautner, *The Active Forms of Silica (Silica-Gel) and their Capacity for Adsorption* (Zeitschrift für angewandte Chemie, 1927, vol. 40, pp. 428-433). The production and properties of silica-gel are discussed with notes on the technical and scientific applications of active silica, such as the drying of gases.

Blast-Furnace Stoves.—J. C. Hayes, *New Heat Interchanger for Blast-Furnace Gas* (Freyn Design, Feb. 1927, pp. 11-12). Brief particulars are given of a method of drying and heating blast-furnace gas after washing. The gas from the washer passes through small diameter tubes, so arranged as to cause the gas to pass at a uniform rate through each tube. The products of combustion from the

hot-blast stoves are passed across the outside of the tubes. A system of flushing keeps the tubes free from any accumulation of sludge.

A. Schack, *Calculation of the Efficiency and the Optimum Load of Blast-Furnace Stoves* (Stahl und Eisen, 1927, vol. 47, June 9, pp. 965-966). Calculations are given for determining the area of heating surface in blast-furnace stoves, given the required total heat consumption while under gas, and other factors.

W. Nusselt, *The Theory of the Blast-Furnace Stove* (Zeitschrift des Vereines Deutscher Ingenieure, 1927, vol. 71, Jan. 15, pp. 85-91). Formulæ for the calculation of heat exchange and temperature conditions in the stove are worked out for five different hypothetical cases.

A. Wefelscheid and H. Rappold, *Interlocked Power Operated Hot-Blast Stove Valves* (Stahl und Eisen, 1927, vol. 47, Aug. 4, pp. 1283-1284). A system of compressed air operated stove valves, rigidly connected and moving in definite sequence, is described. The change-over from gas to blast takes under 30 seconds. This factor of rapidity is important for furnaces with gas power plants or furnaces with only two stoves. The arrangement is also safer for the operators. In cases of breakdown the valves can be hand-operated. If necessary, all the stoves can be operated from a central control.

Blast-Furnace Gas Cleaning.—A. Grounds and H. W. C. Henderson, *Electrical Precipitation* (Paper read before the South Wales Institute of Engineers, Nov. 22, 1927, 45 pp.). It is now generally recognised that the gas from blast-furnaces must be cleaned before it can be used satisfactorily. Electrical precipitation has the advantage of dealing with individual particles of dust and suspended matter without in any way affecting the gas itself, and the sensible heat of the gas can be retained, whereas in wet washing and bag filtering the sensible heat is lost. The present paper describes the Lodge-Cottrell electrical installation, which is of two types. The first type, known as the plate type treater, consists of a number of vertical plates forming the collecting electrodes; in the second type, known as the pipe-treater, the collecting electrodes comprise a number of earthed metallic tubes, down the axes of which insulated wires are suspended, the gases being led through the tubes and the dust precipitated on the inside surface through the action of the electric discharge. Descriptions are given of Lodge-Cottrell installations at the following plants: The Workington furnaces of the United Steel Companies, where a gas volume of 4 million cu. ft. per hr. from three furnaces is rough-cleaned, the total power consumption being about 50 kw.; at the works of the Darwen Mostyn Iron Co., where the temperatures are higher than at Workington, and finally at the works of the North Lonsdale Iron and Steel Co., Ulverston. This latter plant, of the plate type, has been in operation over five years. It treats 4 million cu. ft. of gas per hr. from two hematite furnaces and collects over 70 tons of flue-dust per week. The total power consumption is approximately 36 kw. Another plant is in operation at

Stewarts and Lloyds' furnaces at Kettering. The paper concludes with references to the application of the Lodge-Cottrell process to sulphuric acid plants, zinc, tin, lead, and copper smelting works and cement kilns.

New Gas-Washer for Ohio Furnace (Iron Age, 1927, vol. 120, July 28, pp. 198-200). Illustrated particulars are given of the new blast-furnace and gas-washer recently completed at the Steubenville, Ohio, plant of the Wheeling Steel Corporation. The furnace is 92 ft. in height, the diameter of the hearth is 21 ft. 6 in., the diameter of the bosh 25 ft., and the diameter of the stock line 17 ft. 6 in. The furnace is equipped with 16 tuyeres, and the copper cooling plates go as high as the mantle. The furnace top equipment includes a steel plate gas seal, a McKee revolving distributor with self-contained worm and gear drive, and automatic gauge rod. The bells are raised and lowered by electrically operated hoists. The gas-washer consists of a cylindrical steel shell 72 ft. high and 18 ft. in diameter, divided into six compartments or stages. Each stage comprises a complete separate gas-washer equipped with individual rotor unit and drive mechanism. Gas is admitted to the washer just above the water-line of the bottom compartment, and passes upward through the spray of each successive stage. Baffle plates are provided throughout the interior of the washer to govern the flow of the gas and to distribute it so as to get the maximum efficiency from the various sprays. A curtain wall, made up of a series of vertical channels, is installed in the top cone of the washer, to baffle further the flow of gas and thus remove entrained moisture.

Gas-Cleaning Plant at the Devonshire Works (Iron and Coal Trades Review, 1927, vol. 115, Sept. 2, p. 331). The general layout of this gas-cleaning plant is shown. The plant is installed in tandem with the furnaces, the gases being led into three scrubbing towers, each 15 ft. in diameter and 72 ft. high. From the scrubbing towers the gas is passed through three Theisen washers, and then through cyclone dryers, where all trace of moisture is removed.

G. W. Hewson, *Blast-Furnace Gas: Calculations to Determine the most Efficient System of Cleaning* (Fuel Economist, 1927, vol. 2, June, pp. 503-505; July, pp. 553-554; Sept., pp. 669-670).

Manufacture of Ferro-Silicon.—J. Silberstein, *The Manufacture of Ferro-Silicon in the Electric Furnace* (Fuels and Furnaces, 1927, vol. 5, June, pp. 751-754). The author describes electric furnace practice for the manufacture of ferro-silicon. In the production of 50 per cent. ferro-silicon it has been found that the product disintegrates, thereby generating poisonous gases. The disintegration takes place rapidly in a moist atmosphere. The silicon content has also a marked influence on the velocity of disintegration, and manufacturers generally keep the percentage of silicon somewhat below 50 per cent. In order to prevent disintegration the following precautions have to be taken: (a) careful selection of raw materials of high purity; (b) keeping

the mixture of the raw materials in a porous condition so as to allow gases, formed by the reactions, to escape; (c) pouring into chilled moulds. Theoretically, the energy necessary for the reduction of 1 lb. of silicon from silicon dioxide is 2900 large calories. It has been calculated that the theoretical power consumption for producing 1 lb. of 50 per cent. ferro-silicon in the electric furnace is approximately 0.94 kw.-hr.

Iron Industries of Various Countries.—F. S. Wilkinson, *The South Staffordshire Iron and Steel Industry* (Presidential Address to the Staffordshire Iron and Steel Institute, Oct. 8, 1927).

A. J. Reynaud, *Iron and Steel Centres in France* (Iron Age, 1927, vol. 120, Sept. 1, pp. 540–542). A brief survey is given of the chief iron- and steel-making districts of France. Maps are included showing the location of the ore and coal deposits and also the plants in the Briey and Longwy districts.

D. Baker, *Some Features of Australian Blast-Furnace Construction and Practice* (Proceedings of the Engineers' Society of Western Pennsylvania, 1927, vol. 43, June, pp. 255–261). A brief account is given of the development of the blast-furnace plant of the Broken Hill Proprietary Co., Ltd., Melbourne, with some details of the various units comprising the plant. Some of the features described more fully are: the reduction of coke-handling to a minimum by the use of an inclined coke bench and narrow-gauge coke hoppers, the protection of furnace hearths with copper cooling pipes laid in the brickwork, the protection of the bosh wall with a cast steel jacket carrying bronze cooling plates, and the support of the lining of the blast-furnace at three points—namely, at the bottom, at the mantle, and with a secondary mantle ring under the upper inwall.

C. S. Fox, *India's Resources in Raw Materials for a Domestic Iron and Steel Industry* (Paper read before the Second Empire Mining and Metallurgical Congress, Canada, 1927). A review of the mineral resources of India, including particulars of the operations of the Bengal Iron Co., Ltd., the Tata Iron and Steel Co., Ltd., and the Indian Iron and Steel Co.

G. M. Slight, *An Iron and Steel Industry in Chile* (Iron and Coal Trades Review, 1927, vol. 115, Aug. 26, p. 295). Chile possesses excellent iron ore deposits, among them the Tofo mines, but it lacks a supply of metallurgical coke. In the period 1908–1910 attempts were made to produce pig iron at the Corral plant, using the Prudhomme process. This was based on the smelting of iron ore by charcoal, the charcoal being produced at the top of the blast-furnace from wood by means of the waste heat. Though this process gave actual results, it did not prove to be an economical one. Since the war a study has been made of the latest developments in the iron industries of other countries, and the conclusion has been reached that the electric smelting process would be ideal for conditions in Chile. An investigation has

been made of the hydro-electric power possibilities of the Huilo-Huilo Falls on the river Hui, to the east of Valdivia, an option for the purchase of the Corral plant has been obtained, and an agreement has been reached with the J. G. White Engineering Corporation of New York for the construction of plant. A company is being floated under the name of Cia. Electro-Siderúrgica e Industrial de Valdivia, and it is hoped to commence construction at the end of this year; electric power will be produced at the Huilo-Huilo Falls. A power station of 32,000 H.P. is to be built, and electricity will be transmitted to Corral at 110,000 v., 50 cycles. At Valdivia a sub-station with a capacity of about 7000 H.P. will deliver power to the local industries. The plant at Valdivia will comprise three electric furnaces, a battery of open-hearth furnaces, and rolling-mills.

I. J. Moltkehanen, *The Electrochemical and Electrometallurgical Industries of Norway, 1902-1927* (Paper read before the American Electrochemical Society, Sept. 1927). A large variety of electrolytic and electrothermic processes have been in operation in Norway for a good many years. Zinc, fixed nitrogen, chlorine, hydrogen, sodium, aluminium, carbide, ferro-alloys, carborundum, and corundum are among the electrochemical products produced in Norway at the present time.

S. A. M. Bresgunow, *Development of the South Russian Blast-Furnaces* (Stahl und Eisen, 1927, vol. 47, June 9, pp. 973-975). Details are given of the growth of the South Russian iron industry from 1885 to 1913, with number and dimensions of furnaces, names of localities, and capacities of production.

H. Kalpers, *The Electrical Production of Pig Iron in Sweden* (Dingler's Polytechnisches Journal, 1926, vol. 341, Aug., pp. 177-179). The production of pig iron in Sweden and the operation of the furnaces are described. The Uddeholm Works have five electric furnaces, the Stora Kopparbergs Company have six, at Tröllhätten there are four, and at the Porjus-Smält Works there are three.

T. W. Robinson, *The Economic and Social Development of the American Iron and Steel Industry* (Paper read before the Iron and Steel Institute, Sept. 1927: this Journal, p. 13).

P. M. Tyler, *Ore and Fuel Cost Here and Abroad* (Iron Age, 1927, vol. 119, June 2, pp. 1593-1595). A discussion of the factors influencing the costs of blast-furnace raw materials in United States, Great Britain, France, Germany, Belgium, and Luxemburg.

F. W. Jessop, *Progress by Reason of Electricity* (Speech delivered before the "Big Ten" Club of Cleveland, U.S.A.; abstract, Blast-Furnace and Steel Plant, 1927, vol. 15, May, pp. 227-228). An outline of developments in the iron and steel industry made possible by the use of electricity.

Historical.—H. C. Evans, *Surrey Ironworks* (Foundry Trade Journal, 1927, vol. 35, June 16, pp. 505-506). Brief particulars are

given of the ancient Surrey iron industry. The date of the first definite mention of ironworks in the county is 1553. In that year the sale is recorded of ironworks at Ewood.

The Quality of Iron and the Forging Processes of the Gallo-Roman Period (Génie Civil, 1927, vol. 90, Feb. 19, pp. 198–199). An account of an investigation by Frémont on three ancient battle axes, to determine the quality of the metal of which they were made.

B. Neumann, *Roman Damascene Steel* (Archiv für das Eisenhüttenwesen, 1927, vol. 1, Sept., pp. 241–244). By the courtesy of the director of the Schleswig-Holstein Museum, the author has been able to examine parts of ancient Roman swords found at Nydam, on the Alsensund, in Denmark, in 1859, 1862, and 1863. The discovery consisted of three shiploads of weapons, among them 100 swords, the hilts of which showed an artistically worked structure. The date of the sinking of the ships was about A.D. 220. On the sword examined it appeared that damascened strips had been welded on to a harder steel strip, and that the hard steel edges had also been welded on. A troostite-martensite structure in one of the edges proves that the Romans understood the art of hardening steel. A number of micrographs accompany the description.

II.—BLAST-FURNACE SLAGS.

Tests of Slag.—A. Guttmann, *Causes of the Disintegration of Blast-Furnace Slag, and Tests of its Stability* (Stahl und Eisen, 1927, vol. 47, June 23, pp. 1047–1048). The best test for constancy of volume of slag is to examine a good specimen by the light of the quartz lamp, and also to note its behaviour when placed in water. In the former case, if clusters of small bright, light yellow spots or reddish or cinnamon spots appear on a bright or dark violet ground, the slag is friable and its instability is due to the presence of an unstable form of bicalcium-silicate. If only a few tiny spots of yellowish or brown colour appear evenly distributed, there is no fear of disintegration. Should there be no fluorescent appearances, the slag should then be placed in water, when, if it contains an excess of iron compounds, it will disintegrate. Disintegration in water never takes place if the total iron (calculated from the iron oxides) is under 1.5 per cent., but always occurs if the total iron exceeds 3 per cent. The water test is a simpler method than chemical analysis.

Composition and Utilisation of Slags.—R. S. McCaffery, J. F. Oesterle, and Leo Schapiro, *Composition of Iron Blast-Furnace Slags* (American Institute of Mining and Metallurgical Engineers, 1927, Technical Publication No. 19; *abstract*, Jour. I. and S.I., 1926, No. II. p. 549).

A. Stansfield and J. E. Morrison, *Blast-Furnace Slags containing Titanium* (Transactions of the Royal Society of Canada, 1926, vol. 20, pp. 439-443). The fusibility of mixtures of CaO , SiO_2 , Al_2O_3 , TiO_2 , and Ti_3O_5 in varying proportions was determined in order to obtain information regarding the smelting of titaniferous iron ores. The Al_2O_3 content was kept constant at 10 per cent. of each mixture. Triangular graphs of the two series SiO_2 , Al_2O_3 , Ti_3O_5 , in a reducing atmosphere, and SiO_2 , Al_2O_3 , TiO_2 , in an oxidising atmosphere, are given. The formation of a refractory compound of titanium under conditions obtaining in the blast-furnace (probably a nitride of titanium) is recorded.

R. Schönhöfer, *The Manufacture of Artificial Brick from Blast-Furnace Slags by the Activating Process* (Archiv für das Eisenhüttenwesen, 1927, vol. 1, Oct., pp. 267-271). The mechanism of the activating process (Weck process) is discussed. The hydraulic properties, inherent in most blast-furnace slags, can be activated and the material agglomerated by treatment in a pug-mill if slightly moistened. The possible applications of the activated material are considered. Mortar, concrete for foundations, road surfacing material, bricks and cements can all be prepared. In discussing the adaptability of the various slags, it is noted that acid slags can be used in large proportions, and that good brick may be made from basic iron slags with additions of other slags. Finally, the activating plants at Lübeck, Ymuiden, and Borsigwerk are fully described.

C. E. Bardsley, *Utilisation of Blast-Furnace Slag in Highway Improvement* (Bulletin of the School of Mines and Metallurgy, University of Missouri, 1926, vol. 10, Nov., No. 1, 115 pp.). A concise description is given of the manufacture of slag from the processes at the blast-furnace up to the time it becomes a constructional material. The treatment and uses of slag are dealt with, and specifications for slag in highway construction are discussed. Tests of slag are also discussed, and a bibliography is included of literature on blast-furnace slag.

H. Burchartz and G. Saenger, *Trials with Lump Blast-Furnace Slag as Railway Ballast Material* (Archiv für das Eisenhüttenwesen, 1927, vol. 1, Sept., pp. 177-186). Comparative tests were carried out with lump slag and quarried ballast for water absorption, chemical effect on wood and iron sleepers, resistance to frost, Rudeloff's test for resistance to blows, and pressure. A draft specification, governing manufacture and inspection, was prepared by the committee, in which it was suggested that the Rudeloff pressure test be specified instead of the tests on a prepared specimen. Numerical values were given for the acceptable degree of fragmentation.

H. Hermanns, *Recent Practice in the Utilisation of Iron-Bearing Slag* (Wärme, 1927, vol. 50, Apr. 22, pp. 283-287). Particulars are given of German plant for the magnetic recovery of iron from waste slag heaps.

III.—DIRECT PROCESSES.

C. E. Williams, E. P. Barrett, and B. M. Larsen, *Production of Sponge Iron* (United States Bureau of Mines, 1927, Bulletin 270). The present experimental work of the Bureau deals only with the production of sponge iron by heating iron ores at low temperatures, using solid carbon as the reducing agent. In addition to tests in muffle furnaces of various sizes, experiments ranging from small-scale laboratory work to trials of semi-commercial installations were made with rotating metal-tube furnaces. Low heat-flow capacity seemed to be the cause of failure of the muffle-heated type of furnace. Because of the importance of rapidity of heat flow in the treatment of a large charge of ore and coal, it was decided that the best type of furnace for commercial operation was one in which the charge came in direct contact with the gases of combustion. The rotary kiln offered a simple and workable type of construction for such a furnace.

Preliminary tests in a small, intermittently operated kiln showed that rapid reduction of the ore was obtained. Although the gas stream above the rolling charge in the kiln was oxidising to iron, the hot particles of carbon maintained a strongly reducing atmosphere within the charge. Rapid heating and thorough stirring were obtained, and complete reduction of the crushed ore at 900° to 950° C. usually required 40 to 60 minutes.

For continuous operation a two-diameter rotary kiln was then developed; the charge was fed continuously into the upper end, and the reduced product was discharged continuously at the heating end of the enlarged section. The two-diameter construction proved most suitable, because the feed was heated rapidly to reduction temperature as it passed in a thin layer through the preheating section, and was then held in the enlarged section for an hour in a thick layer within the narrow range of temperatures required for rapid reduction without fusion and sticking.

The Bulletin also contains a review of the important types of furnaces or processes that have been tried in the past, an outline of the theory and the fundamental data involved in the problem of low-temperature reduction of iron ores, and methods for the determination of metallic and ferrous iron in sponge iron. The economics of sponge iron production are also discussed. That sponge iron may be widely used in certain chemical and metallurgical operations that require finely divided metallic iron of high porosity and strong chemical reactivity is conceivable. Sponge iron has many advantages as a precipitant of metals from solution. Such use in copper metallurgy has been advocated for many years, and interest in it has been revived recently.

Interest is also being shown in the possibility of using sponge iron in place of the more common forms of finely divided iron as a reagent in processes of organic chemistry; the iron oxide formed as a result of

the reduction reaction, now a waste product, would be converted to sponge iron and thus used again.

Some work is being done both in the United States and in Canada on the recovery of titanium oxide from ilmenite, $(\text{FeTi})_2\text{O}_3$, by reducing the iron to the metallic state and leaching it with acid or a ferric salt solution, leaving the TiO_2 in a purified form for use in the manufacture of paint.

Making Sponge Iron in Japan (Iron Age, 1927, vol. 120, Oct. 6, pp. 937-938). Brief particulars are given of the experimental plant in operation at Kuji, Japan, for the low-temperature reduction of iron sand. Sponge iron is produced by the Thornhill and Anderson process.

F. Wüst, *The Direct Production of Iron* (Stahl und Eisen, 1927, vol. 47, June 2, pp. 905-915 ; June 9, pp. 955-965). The article gives a well-illustrated description of the Edwin, the Wiberg, the Bureau of Mines, and the Hornsey apparatus and processes for the direct reduction of iron, with a comparison of their principles and methods of working, of their economy and the nature of the product. Details of trial runs are given. Both the Edwin and the Wiberg processes have a promising future at least in the countries of their origin, where the conditions are favourable on account of the character of the ore and a plentiful electric supply.

P. Longmuir, *The Direct Production of Pure Iron* (Paper read before the American Electrochemical Society, Apr. 1927). The most important results obtained by various investigators in the direct production of iron are briefly reviewed, and particulars are given of the Thomas Rowlands process. According to the author, this process offers decided advantages over other older processes. The primary advantage is in the direction of the recovery of the whole of the iron in a state of metallic purity. The main stages of the process are : Distillation of coal ; preliminary reduction of iron ore ; complete reduction of iron ore ; magnetic separation of the metallic iron ; revivification of spent gases.

F. Hodson and O. Smalley, *Development in the Low-Temperature Reduction of Iron Ore* (Paper read before the American Electrochemical Society, May 1927). Brief particulars are given of the following processes : Greaves-Etchells, Hornsey, Croese, Edwin, Grönwall, Flodin, Bardue, and the process of the Triumph Steel Company.

O. Smalley and F. Hodson, *The Manufacture of Steel in "One Process" Direct from Ore* (Paper read before the American Electrochemical Society, May 2, 1927). The authors describe two processes, which though dissimilar in actual operation, demonstrate the commercial feasibility of the manufacture of superior steels direct from ore in one process. The Pehrson-Prentice process is continuous, the ore being reduced in a primary rotary furnace and refined in an entirely new type of arc-resistance furnace. In the Carsil process, a Greaves-Etchell furnace only is used, and steel of superior quality has been produced from New Zealand titaniferous iron sands. Particulars are included of the properties of Carsil steel.

C. G. Fink and C. L. Mantell, *A Laboratory Hydrogen-Oxygen Generator* (Paper read before the American Electrochemical Society, Sept. 1927). In work on hydrogen reduction of ores, it is often extremely desirable to have a constant pressure hydrogen source, which once set will produce hydrogen over long periods of time without requiring attention or adjustment. For experimental investigations with hydrogen gas the use of compressed gas in steel cylinders is objected to, on account of the difficulty of maintaining a constant supply at constant pressure over long periods of time. On the other hand, the installation of standard electrolytic cells involves considerable expense. Accordingly, the authors describe a simple glass cell, using nickel electrodes in a 30 per cent. NaOH solution. At 15 amp. 5.66 litres per hr. of hydrogen were produced.

FOUNDRY PRACTICE.

General Foundry Practice.—W. Mathesius, *The Cupola in Theory and Practice During the Last Two Decades* (Stahl und Eisen, 1927, vol. 47, July 28, pp. 1229–1241). The published work of Buzek, Belden, Cook, Wüst, Braun and Hollender, Wagner, Piwowarsky, and Meyer is considered, and their results checked by quantitative comparison. After fundamental explanation of the processes of combustion, it is shown that, with a good coke, the most efficient working is obtained with a coke consumption equal to 8 to 10 per cent. of the charge, air 100–120 cu. m. per sq. m./minute, and a melting capacity of 10–12 tons per sq. m./hour. Increased consumption of coke lowers the melting capacity. The output at low blast pressure increases in proportion to the blast volume, but when an optimum volume is exceeded it does not further increase. It is also shown why in an ordinary cupola white iron cannot be superheated, but that grey iron may be heated up to 1450°. The difficulties in attaining high temperatures, either by preheating or by oxygen enrichment, are noted. Conclusions are drawn as to the design and management of cupolas.

P. H. Wilson, *The Importance of Air Control in Efficient Cupola Practice* (Paper read before the Institute of British Foundrymen: Foundry Trade Journal, 1927, vol. 36; July 14, pp. 49–54; July 28, pp. 83–88). The author describes a number of experiments the results of which emphasise the importance of scientific control of air blast in cupolas. Some of the conditions which affect the efficient working of cupolas are also briefly discussed.

F. K. Vial, *Hot-Blast Applied to the Cupola* (Iron Age, 1927, vol. 120, Oct. 20, pp. 1071–1076). The author describes the practice of the Griffin Wheel Co., Chicago, in the use of hot-blast for cupolas. A standard cupola is used having an upper wind-box fitted just below the charging door. A portion of the cupola gases is drawn off through this wind-box and passed to the combustion chamber of a preheater. The waste gases are drawn off through tubes in the preheater and up through an exhaust fan. The air is heated by contact with the tubes and enters the cupola through the ordinary wind-box. The application of the hot-blast to the Griffin cupolas has been in successful operation on a regular production basis for a period of two years, melting approximately 200,000 tons of iron. The results obtained from a hot-blast cupola and from an ordinary cupola are shown, and they indicate that combustion is more complete with hot-blast than with cold-blast. Heat balances for the two types of cupolas are included. It is claimed that the heating of the blast results in a decided saving of coke, power,

and labour, with increased control of melting conditions, and ensures greater uniformity in the finished product.

H. W. Dietert, *Correction of Cupola Operation by Means of Cupola Temperature Recorder* (Paper read before the American Foundrymen's Association, June 1927). The author gives particulars of a temperature recorder which may be adapted to either a continuous or intermittently operated cupola. A number of iron temperature charts are given, showing some of the typical errors of cupola operation, and the manner of correcting such operation in order to give a uniform iron temperature throughout the heat is explained. Various causes of rapid changes of iron temperature in the cupola are listed.

W. Wenzl and F. Morawe, *Temperature Measurements of Liquid Cast Iron, Basic Pig, and Steel* (Stahl und Eisen, 1927, vol. 47, May 26, pp. 867-871). In the case of liquid foundry iron comparative measurements with thermo-elements and optical pyrometers showed that the readings of the Holborn-Kurlbaum pyrometer in general lie about 10° lower than those of the thermo-elements. The iron-constantan and iron-nickel elements were in good agreement with the platinum, platinum-rhodium elements. Measurements made on basic pig at the furnace tap-hole, on mixer metal, and on converter steel were also about 5° lower when read with optical instruments than with the thermo-elements. The small differences in the case of practical foundry work seem to indicate that the surface of the metal is never really clean, but always covered with an oxide film. The usual correction coefficient for optical pyrometers, which would be about 100° , is not applicable in this case, as it would give a reading by nearly that much too high.

P. Bardenheuer and A. Kaiser, *The Influence of Auxiliary Coal-Dust Firing on Melting in the Cupola* (Mitteilungen aus dem Kaiser-Wilhelm-Institut für Eisenforschung, 1927, vol. 9, No. 16, pp. 247-264; Stahl und Eisen, 1927, vol. 47, Aug. 25, pp. 1389-1395). Comparative cupola melting tests with and without auxiliary coal-dust firing are reported. In the former tests the powdered coal was introduced into the cupola through openings adjacent to the tuyeres. Very careful material and heat balances were prepared, and the results obtainable in practice were determined. The tests were all carried out in the one cupola. By reducing the coke in the charge from about 11 per cent. to about 7 per cent. and adding from 0.8 to 0.9 per cent. of coal-dust, the following improvements were obtained: the output and the efficiency were much increased, the sulphur content was reduced owing to the smaller quantity of coke used, and the slag was decreased on account of the smaller quantities of coke and limestone required. So far, no disadvantages have made themselves apparent. The oxidation of iron, manganese, and silicon appeared to be about the same as that occurring in normal practice, and the strength properties of the cast iron were hardly affected by the introduction of the coal-dust, any change being rather in the direction of an improve-

ment than the reverse. A comparison between coal-dust firing and oil firing of the cupola shows that these two methods are about equally advantageous, though the former is superior to the latter in regard to control and regularity of working.

P. Bardenheuer, *On Combustion in the Cupola and the Manner in which it is Influenced by Coal-Dust Firing* (Giesserei Zeitung, 1927, vol. 24, Aug. 15, pp. 451-455; abstract, Foundry Trade Journal, 1927, vol. 36, Sept. 22, pp. 259-261).

U. Lohse, *Cupola with Auxiliary Coal-Dust Firing* (Zeitschrift des Vereines Deutscher Ingenieure, 1927, vol. 71, Feb. 12, pp. 233-235). An illustrated description is given of the cupola with coal disintegrator attached. The coal-dust is blown through tuyeres at the height of the melting zone. A very considerable economy in coke is reported to result; coal-dust equal in weight to 1 per cent. of the charge is said to reduce the coke consumption by 40 per cent.

J. T. Mackenzie, *The Properties of Coke Affecting the Cupola Melting of Steel* (Paper read before the Institute of British Foundrymen, July 1927: Foundry Trade Journal, 1927, vol. 36, July 7, pp. 15-18). The author is concerned chiefly with the total carbon absorbed by all-steel charges when melted in a cupola with various cokes. The results of tests indicate a carbon equilibrium between the coke and the iron, but further tests are in course of completion and will be published later.

W. E. Dennison, *A Critical Analysis of Cupola Practice from the Angles of Coke Combustion and Size of Charges* (Foundry Trade Journal, 1927, vol. 36, Aug. 25, pp. 178-179).

H. Pinsl, *Trials with Automatic Gas Analysis in Cupola Working* (Die Giesserei, 1927, vol. 14, June 4, pp. 374-384). A lengthy account of experiences with the Ados electrically driven apparatus and with the Monometer recording appliances in the automatic analysis of the waste gases of cupolas.

P. Dwyer, *Superheats Direct Metal Electrically* (Foundry, 1927, vol. 55, Sept. 15, pp. 710-715, 737). *Using Direct Metal in Foundry* (Iron Age, 1927, vol. 119, June 30, pp. 1869-1872, 1928). Illustrated particulars are given of the plant and practice at the foundry of the Ford Motor Co., Fordson, Michigan. The metal used for pouring moulds consists of about 50-60 per cent. of blast-furnace metal and the balance of cupola metal. This is drawn from a 400-ton mixer and is brought up to correct pouring temperature in acid electric furnaces. Two cupolas of unusual size are provided, having 120-in. shells lined down to 96 in. Up to 25 tons of iron can be tapped from each cupola at one time. By varying the proportions of blast-furnace and cupola metal it is found possible to control the silicon more closely than is usual in ordinary cupola operation, and the castings obtained are of more uniform quality.

H. Hanemann, *Theoretical Principles Involved in the Superheating of Grey Cast Iron* (Stahl und Eisen, 1927, vol. 47, Apr. 28, pp. 693-695; abstract, Foundry Trade Journal, 1927, vol. 36, Aug. 4, pp. 108-109).

Poumay, *Comparative Studies of Cupola Working* (Revue de Fonderie Moderne, 1927, May 25, pp. 136-140). A new design of cupola has been patented by the author under the name of the Poumay cupola, and the results of the working of this new cupola are compared with those of the ordinary cupola. The drawing up of heat balances and their signification, the factors determining economy of cupolas, and the determination of heat required to melt 100 kg. of pig iron are discussed.

Important Development in Cupola Practice (Foundry Trade Journal, 1927, vol. 35, May 26, pp. 433-434). Details are given of the operating results obtained with a cupola operated on the Poumay system. The cupola had originally two rows of tuyeres, and fourteen additional tuyeres were added arranged in spiral form, the highest of these reaching to within approximately 4 ft. of the charging door. When working on a 75 per cent. semi-steel mixture the results of cupola operation showed a saving of 30 per cent. of coke as compared with an ordinary cupola.

E. W. Dörfurt and T. Klingenstein, *The Effect of Fluorspar as an Addition in the Cupola* (Stahl und Eisen, 1927, vol. 47, Jan. 27, pp. 128-133; abstracts, Metallurgist, July 29, p. 111; Journ. I. and S.I., 1927, No. I. p. 852).

E. Hamélius, *The Refining and Desulphurising of Cast Iron* (Revue de Fonderie Moderne, 1927, vol. 21, Apr. 10, pp. 56-57; Génie Civil, 1927, vol. 90, Mar. 5, pp. 247-248). The author describes a method of refining, which has for its object the reduction of inclusions and obtaining homogeneous castings with improved mechanical properties. In this process the cupola is provided with a fore-hearth and a slag collector. The metal is syphoned off into the fore-hearth, where it is allowed to remain awhile in contact with fresh easily fused slag of soda or borax. The fore-hearth is heated by gases from the fusion zone of the cupola.

P. Bardenheuer and H. Ostermann, *The Influence of Alkaline Salts upon Molten Iron* (Die Giesserei, 1927, vol. 14, May 7, pp. 305-307; abstract, Foundry Trade Journal, 1927, vol. 37, Oct. 13, p. 34).

G. S. Evans, *Sodium Carbonate Compounds affect Refractory Linings* (Foundry, 1927, vol. 55, Aug. 15, pp. 632-634). The author deals with the use of alkalis for the refining of cast iron, and outlines briefly the effect of sodium compounds on refractory linings.

G. S. Evans, *Effect of Purite on Refractories* (Paper read before the American Refractories Institute, May 18, 1927: abstract, Blast-Furnace and Steel Plant, 1927, vol. 15, July, p. 362). Purite is fused soda ash, cast into 2-lb. bricks for use in the foundry industry. The fused material will not absorb moisture, and melts gradually in contact with molten iron which prevents any possibility of explosion, or injury to operators by flying alkali dust. Purite is of value as a refining agent for cast iron owing to its strong basicity, low melting point, and extreme activity at comparatively low temperatures. Its action on free silica or silicates in mud grouting is quite vigorous at the temperature of cupola metal,

but is not so pronounced on burnt brick. Experimental ladle linings made up with different brands of firebrick and plastic lining materials have not so far developed any outstanding results. Alkalies are also used nowadays for refining air-furnace malleable iron. The sulphur content is reduced, and some deoxidation and removal of slag inclusions also occur.

F. Russell, *The Lining of a Cupola* (Paper read before the Institute of British Foundrymen: Foundry Trade Journal, 1927, vol. 37, Oct. 13, pp. 24-25). According to the author monolithic linings are best for cupolas, and they should consist of a mixture of hard, comparatively large refractory lumps with a high refractory clay or other suitable binding medium.

W. B. Coleman, *Carbon Characteristics of Copper-Bearing Pig Iron* (American Institute of Mining and Metallurgical Engineers, 1927, Technical Publication No. 11, pp. 12-23). A brief discussion of the properties of copper-bearing pig irons, and the effect of remelting in the cupola on the structure. A copper-bearing pig iron is highly adapted for the manufacture of small castings. Such pig iron shows a low Brinell hardness, good transverse and deflection tests, and a high total carbon content.

F. G. Steinebach, *Alloys Iron Electrically* (Foundry, 1927, vol. 55, June 1, pp. 433-435, 439). An account is given of the practice of the Vulcan Mold and Iron Co., Latrobe, Pa. Various types of ingot moulds are produced from cupola metal, and the methods of moulding are outlined. For certain other types of castings, nickel-chromium cast iron is melted in an electric furnace. The chromium is added in the form of ferro-chrome and the nickel in the form of pure nickel. The chromium content ranges from 0.5 to 15 per cent. and the nickel from 1 to 10 per cent. The tensile strength of the iron is high, averaging about 50,000 lb. per sq. in. Tests have shown that it is several times more resistant to wear than ordinary grey iron.

A. Reynaud, *The Second International Foundry Congress (Detroit, September 27 to October 1, 1926)* (Revue de Métallurgie, Mémoires, 1927, vol. 24, Aug., pp. 443-462; Sept., pp. 516-540). The author presents long abstracts in French of the principal papers presented at the meetings.

F. Brandenburg, *Notes on Methods for Producing Clean and Sound Castings* (Die Giesserei, 1927, vol. 14, May 28, pp. 353-354). By fitting a feeder head on to the top of the runner an even and gentle flow of metal into the mould is ensured. The upper surface of the feeder head is dished out in the form of a funnel, the runner leading out of it, not from the bottom, but high up on the side. When the poured metal reaches a certain height in the funnel, it then begins to flow down into the mould. Another apparatus in the form of a tun dish for suspending over the mould is also illustrated and described.

Improving the Quality of Grey Cast Iron (Revue de Fonderie Moderne, 1927, vol. 21, Aug. 10, pp. 257-262). The various physical and chemical

methods of treating cast iron are dealt with, including graphitisation, the Lanz process for the production of pearlitic cast iron, and the Corsalli and Dechesne methods.

E. Piwowarsky, *Progress in the Production of High-Duty Cast Iron* (Bulletin of the British Cast Iron Research Association, July 1927, No. 17, pp. 8-18).

J. Mehrstens, *Cast Iron for Machine Construction and Improvements in Melting Practice in Iron Foundries* (Maschinenbau, 1927, vol. 6, Feb. 17, pp. 196-201). A discussion of the properties of high-duty cast iron and melting furnace practice, including the after-treatment of the molten iron and the design of castings.

C. Curry, *Test-Bars to Establish the Fluidity Qualities of Cast Iron* (Paper read before the American Foundrymen's Association, June 1927). The author reviews the work of other investigators, and describes his own experiments in which a modified form of spiral test-bar was used.

D. M. Houston, *Nickel Changes Properties of Grey Cast Iron* (Foundry, 1927, vol. 55, May 15, pp. 399-401). The author explains the effect and use of nickel in cast iron. The economic phases of nickel additions are discussed, and several examples of results obtained in operating foundries are given. A simple device which is attached over the cupola spout to facilitate the addition of nickel to the ladle and to make the additions more uniform is described.

S. R. Robinson, *Making Chilled Rolls* (Foundry Trade Journal, 1927, vol. 36, Aug. 4, p. 109). The author records his experience in the manufacture of chilled iron rolls, and discusses briefly several problems relating to this subject.

L. Audo, *Note on the Manufacture of Steam Cylinders for Locomotive and Piston Rings by the Paris-Orleans Railway Company* (Paper read before the Institute of British Foundrymen, July 1927: Foundry Trade Journal, 1927, vol. 36, pp. 7-14). The author describes the manufacture of high tensile cast iron in the cupola from steel, pig, and scrap mixtures, as practised by the Paris-Orleans Railway Co. This material is being used a great deal on the Continent in place of cold-blast pig iron mixtures. The lack of homogeneity of semi-steel made in the cupola is remedied by a preliminary pigging and remelting before casting. The manufacture and testing of cylinders and piston rings are dealt with, and the results of wear in service are tabulated.

Specialises in Anvils for Eighty Years (Foundry, 1927, vol. 55, Sept. 15, pp. 724-729). An illustrated account is given of the melting and moulding practice for the production of anvils as carried out at the plant of the Fisher and Norris Eagle Anvil Works, Trenton, New Jersey. The anvils are poured from an almost exclusively pig-iron mixture. The moulds are made from split patterns in three-part flasks with openings in the end for admission of preliminary heating iron and for an overflow. The drag serves principally as a preheating reservoir, the cheek contains the entire casting, and the cope acts as a cover with suitable openings for the runner near one end and a feeding

head in the centre of the casting. The flat steel plate for the main working face and the curved plate for the horn are placed in position in the drag. The cheek is set in place, followed by the cope, and after the various parts are clamped together the mould is poured. A few minutes before the mould is poured, a sufficient quantity of iron is poured through the small runner in the end to fill the cavity under the steel plate. This raises the plate to a red heat and ensures its amalgamation with the mould metal.

V. Zsak, *The Quantitative and Economic Importance of Acid Steel Castings, in Particular of Acid Electric Steel Castings* (Giesserei Zeitung, 1927, vol. 24, Aug. 1, pp. 413-417). In general, the production of steel castings with phosphorus 0·05 per cent. maximum is more successfully performed in the basic electric furnace, the acid furnace being suitable only when pure raw materials are available—for instance, in a large steelworks, where there would be a plentiful supply of steel scrap. In steel foundries, however, where light steel castings for ordinary purposes are produced, in which phosphorus may go up to 0·10 per cent., the acid electric furnace is undoubtedly the more economical and produces superior metal for castings.

F. A. Melmoth and T. W. Brown, *The Manufacture of a Large Steel Casting* (Paper read before the Institute of British Foundrymen: Foundry Trade Journal, 1927, vol. 36, July 7, pp. 19-22; July 14, pp. 45-48). The authors outline the complete history of the production of a large steel casting, the subject chosen being a cast steel propeller shaft bracket. Each of the operations entailed are dealt with both metallurgically and from the moulding-shop standpoints.

A. Rhydderch, *The Feeding and Gating of Steel Castings* (Foundry Trade Journal, 1927, vol. 36, Sept. 15, pp. 233-236). The author discusses some of the fundamental principles and considerations in the gating and feeding of steel castings.

Auto Jobbing Shop Keeps Floors Busy (Foundry, 1927, vol. 55, July 1, pp. 512-515). An illustrated account of the practice of an American grey iron foundry for the production of light castings used in the automobile industry.

The Status of Electric Furnace in Foundries (Journal du Four Electrique, 1927, vol. 36, June 15, pp. 129-132). Furnaces suitable for use in iron and steel and non-ferrous foundries are dealt with.

P. Longmuir, *Steel Foundry Practice* (Iron and Steel Industry, 1927, vol. 1, June 3, pp. 65-67; July 1, pp. 75-78; Aug. 5, pp. 103-105; Nov., pp. 44-46). The present articles deal with crucible cast steel, the Bessemer process, and the open-hearth process. For the first article of the whole series see *abstract*, Journ. I. and S.I., 1927, No. 1. p. 855.

S. Schey, *The New Steel-Melting Arc Furnace* (Centralblatt der Hütten- und Walzwerke, 1927, vol. 31, May 4, pp. 231-236). Details are given of an electric furnace in operation at the plant of Schäffer and Budenberg, Magdeburg, for the production of high-grade steel castings from scrap.

G. Sepulchre, *The Swedish Rennerfelt Electric Furnace* (Aciers Speciaux, 1926, vol. 2, Sept. 19, pp. 514-519). The furnace and its operation are described and its advantages enumerated.

W. E. Lewis, *Arc Furnace Design Involves Numerous Features* (Foundry, 1927, vol. 55, June 1, pp. 436-439). The author deals with the theory and design of electric arc furnaces for steel foundry practice, and presents data showing three years' operating results of an acid furnace working on cold scrap.

R. Lemoine, *Uses of the Electric Furnace in the Iron Foundry* (Paper read before the International Foundry Congress, Paris, 1927).

K. Sipp, *Cleaning of Castings* (Die Giesserei, 1927, vol. 14, Sept. 3, pp. 601-609). Modern improvements in cleaning of castings are described, and costs of various methods are compared. A jet of water at high pressure, through small nozzles, is most effective, and the cost is one-half that of older methods.

Cleaning and Grinding Castings (Iron Age, 1927, vol. 119, June 30, pp. 1886-1889). An illustrated account of the methods and equipment for the cleaning of castings at the plant of the Maytag Co., Newtown, Iowa.

Defective Castings (Iron and Steel Industry, 1927, vol. 1, June 3, pp. 55-57, 64). The article gives notes and sketches relating to some faulty castings, explains the features of the problems which they present, and records the remedies which were applied. In all cases the adoption of a different method of moulding resulted in a cure of the trouble.

J. W. Bolton, *What Causes Common Defects in Castings* (Foundry, 1927, vol. 55, May 1, pp. 357-360; May 15, pp. 403-405). The author outlines the causes of various defects in castings, and means for their elimination.

J. L. Gibney, *Prevent Flaws in Steel Castings* (Foundry, 1927, vol. 55, July 1, pp. 526-529). The author discusses the use of chill nails and presents typical examples of the manner in which they are used to equalise the speed of cooling between thick and thin sections of small steel castings.

J. M. Haley, *Analysis of Four Hundred Tons of Defective Castings* (Paper read before the American Foundrymen's Association, June 1927). The author presents a classification of defects in grey-iron castings, and discusses methods of controlling production with a view to eliminating them. Of the castings examined, about 70 per cent. of the defects were due to errors in moulding.

Moulding Sands.—J. G. A. Skerl, *The Chemical Constitution and Refractoriness of Moulding Sands* (Bulletin of the British Cast Iron Research Association, Oct. 1927, No. 18, pp. 4-7).

E. R. Young, *Characteristics of Some Steel Moulding and Core Sand Materials* (Paper read before the American Foundrymen's Association, June 1927). The properties of some of the common materials used in making up synthetic moulding and core-sand mixtures are discussed.

Kessner, *Strength of Moulding Sand, with Special Reference to Modern Moulding Operations* (Die Giesserei, 1927, vol. 14, July 30, pp. 525-530). Various methods are described for testing the properties of moulding sand, with special reference to its cohesiveness. A new method of compressing sand, which gives good results, is presented, with illustrations.

E. W. Smith, *Bottle Test for Sand Control* (Paper read before the Ohio State Foundrymen's Association: Iron Age, 1927, vol. 120, Sept. 22, pp. 793-794). The author discusses the importance of the testing and control of foundry sand, and emphasises the value of the simple bottle and vibrator test.

H. L. Campbell, *The Effects of Moisture Absorption on the Properties of Dry-Sand Cores* (Paper read before the American Foundrymen's Association, June 1927). This paper deals with an investigation made to determine the changes in strength and permeability of dry-sand cores when placed in greensand moulds for different periods of time. Nine core-sand mixtures were used, the binders being linseed-oil, rosin, pitch, cereal flours, sulphite liquor, molasses, and dextrin. The conclusions reached were that the deterioration in strength is dependent on the type of binder used and length of time the cores remain in the moist atmosphere. The permeability of dry-sand cores is not changed on exposure to moist air for periods of time up to 24 hrs., and the amount of moisture absorbed from closed greensand moulds is relatively small.

F. C. Scheiber, *Synthetic Moulding Sands in the Malleable Foundry* (Paper read before the American Foundrymen's Association, June 1927). The author describes the practice at the malleable iron foundry of the General Electric Co., Erie, Pa., for the reclamation and treatment of used moulding sand.

M. Kuniansky, *Routine Sand Control in the Pipe Foundry* (Paper read before the American Foundrymen's Association, June 1927). The author discusses sand control tests undertaken in pipe foundries casting large iron pipe. A comparison of the properties of sands used in fifteen different foundries showed wide variations in permeability, dry and green strengths, and moisture contents. Explanations are given by the author as to why these differences existed.

Conveyors and Tempering Arrangements for Foundry Sand Mixing (Iron Age, 1927, vol. 119, June 16, pp. 1738-1740). The methods of mixing new foundry sand with old sand and of conveying the sand through screens and tempering belts into the distributing system, as carried out at the foundry of the Maytag Co., Newtown, Iowa, are described.

Handling Foundry Sand and Coke (Iron Age, 1927, vol. 119, June 9, pp. 1660-1661). A brief illustrated description is given of the sand-and-coke-handling equipment in operation at the foundry of the Maytag Co., Newtown, Iowa.

H. M. Lane, *Sand-Handling Mechanised* (Iron Age, 1927, vol. 120, Aug. 25, pp. 461-465). An illustrated account is given of the system

employed for the mixing and storage of sand at the foundry of the Packard Motor Co., Detroit.

Moulds and Moulding Practice.—U. Lohse, *Progress in Construction of German Moulding Machines* (Die Giesserei, 1927, vol. 14, July 16, pp. 493–499). The article illustrates and describes the latest types of moulding machines.

Pull-Through Moulding Machines (Foundry Trade Journal, 1927, vol. 36, Aug. 18, pp. 144–145). Brief illustrated particulars are given of the pull-through moulding machine, which is particularly adapted both for the production of moulds from deep single patterns, and for the moulding of small objects, such as rollers and other repetition work.

Continuous Moulding Operations with Minimum of Manual Work (Iron Age, 1927, vol. 119, June 23, pp. 1817–1820). Continuous moulding as practised at the foundry of the Maytag Co., Newtown, Iowa, is described and illustrated.

P. Dwyer, *Radiators form Product of New Continuous Foundry* (Foundry, 1927, vol. 55, May 1, pp. 334–338, 366). Melting and moulding practice at the plant of the Landon Radiator Co., North Tonawanda, N.Y., for the production of radiator castings, is described and illustrated.

D. G. Anderson and A. N. Ogden, *Foundry Blacking* (Paper read before the American Foundrymen's Association, June 1927). The authors discuss the need for a test for foundry blackings which will give some definite idea of the quality for foundry use. After some experimental work the authors have developed a method of testing the electrical resistance of a specimen under a standard pressure.

V. A. Crosby, *Core Oil Specifications* (Paper read before the American Foundrymen's Association, June 1927). The author discusses the properties of core oils, and gives particulars of the specifications used by the Studebaker Corporation.

J. Varlet, *Cast Chaplets and Tinned and Untinned Core Irons* (Paper read before the American Foundrymen's Association, June 1927). The paper is divided into two parts, the first relating to coated and uncoated steel core bars, and the second to cast-iron chaplets. The conclusions drawn from tests indicate that iron for tinned chaplets must be pickled before tinning, and that, if untreated irons are used for chaplets, they must be well cleaned and have the oxide scale removed before use.

B. Hird, *Absorbed Gases in Iron and the Creation of Gas Holes in Castings* (Paper read before the Institute of British Foundrymen: Foundry Trade Journal, 1927, vol. 35, June 16, pp. 495–497). The author presents the results of an investigation of the occurrence of blowholes in castings in the immediate vicinity of sprigs, studs, and chaplets. When chills or metal inserts of any kind are used in moulds in contact with the molten metal, vent holes should be made to allow the gases to escape. The amount of gas given off by chills, &c., is

largely influenced by the temperature to which they are raised by the molten metal in the mould before solidification takes place.

E. Longden, *Some Aspects of Foundry Work* (Paper read before the Institute of British Foundrymen: Foundry Trade Journal, 1927, vol. 35, June 2, pp. 463-465; June 9, pp. 475-480). Liquid shrinkage and density of castings, the porosity of moulding sand, and the moulding of various types of castings, are amongst the subjects discussed.

H. Fabre, *The Manufacture of Large Castings* (Revue de Fonderie Moderne, 1927, vol. 21, May 25, pp. 125-131). The author deals with castings of large dimensions which present difficulties in moulding, and gives particulars of the material employed, and methods of pattern making and moulding.

B. Shaw and J. Edgar, *Making a Large Circular Cover* (Foundry Trade Journal, 1927, vol. 36, Sept. 29, pp. 287-288). An illustrated account is given of the operations involved in the moulding of large circular dish-shaped covers.

Continuous Casting of Small Parts (Iron Age, 1927, vol. 120, Aug. 18, pp. 391-393). An illustrated account is given of the layout and equipment of the Elmira Foundry Co., Elmira, New York. A continuous sand-handling and preparation system is in operation, and hand-shovelling is totally eliminated. The moulds are handled and poured on a continuous conveyor of the endless chain type 430 ft. long.

J. H. List, *Making a Large Melting Pot* (Iron and Steel Industry, 1927, vol. 1, July 1, pp. 85-86). The method of making the moulds for the casting which weighed 25 cwt. is described.

G. H. Wright and J. M. Sampson, *A New Type of Mould-Drying Oven* (Paper read before the American Foundrymen's Association, June 1927). Particulars are given of a car-type mould-drying oven in successful operation at the steel foundry of the General Electric Co., Schenectady. The side walls of the oven contain ducts through which the air passes downwards on its way to the interior of the oven and upwards on its return to the fans and steam heating coils. The interior wall of this duct is composed of perforated steel plates. On top of the oven these ducts are connected by well-insulated conductors to two fan blowers and steam heat exchangers. The air is heated in these heat exchangers and is forced down the hollow wall or duct, and across the surface of the moulds to the duct within the opposite wall. When the steam heat is first turned on and the blowers started, steam is injected into the oven until the temperature of the centre of the moulds reaches 180° F. This humidity prevents the skin of the mould from drying, and assures a steady flow of moisture from the interior of the mould to the surface by capillary attraction. The results of tests on the oven are tabulated.

B. Osann, *Considerations on the Design and Working of Drying Stoves and Drying Apparatus in Foundries* (Stahl und Eisen, 1927, vol. 47, Sept. 29, pp. 1597-1606). Explanations are given of the difficulty of scientific treatment of these questions, and the discrepancies

which may be noted among the published data. The theory of the drying process and its practical aspects and control are described. Modern progress and improvements, such as drying processes with solid, gaseous, and liquid fuels, prevention of explosions and drying without fuels, are criticised. Means of effecting economy, exemplified by circulatory drying, regenerators, insulation of walls and doors, blowers, induced draught, utilisation of space, portable driers, continuous working, &c., are discussed.

E. Diepschlag, *The Drying of Moulds and the Thermal Efficiency of Drying Stoves* (Giesserei Zeitung, 1927, vol. 24, Aug. 15, pp. 417-450). Calculations are presented as to the heat requirements for drying stoves of various dimensions, taking account of the heat losses through the walls.

O. Ebling, *Directions for Determining the Efficiency of Drying Stoves* (Die Giesserei, 1927, vol. 14, June 4, pp. 394-398).

Centrifugal Castings.—*Centrifugal Castings for Locomotive Piston-Valve Bushings* (Engineering, 1927, vol. 124, Nov. 4, pp. 580-581). The "Spun-Sorbitic" process, a development of the Hurst-Ball process, is briefly outlined. The centrifugal casting is cooled from a temperature immediately below the melting point by a wet-air blast which causes the microstructure to be sorbitic, so conferring good wear-resisting properties on the metal. Micrographs of various types of centrifugal castings are reproduced.

"*Spun-Sorbitic*" *Cast Iron* (Foundry Trade Journal, 1927, vol. 36, Sept. 1, p. 195). "Spun-Sorbitic" cast iron is a product of the Hurst-Ball centrifugal casting process for cylinder linings and similar engine castings. Brief particulars of its structure are given.

L. Cammen, *Centrifugal Casting of Steel* (Transactions of the American Society for Steel Treating, 1927, vol. 11, June, pp. 915-958). The first portion of the paper deals with the centrifugal casting of tubes, and shows its present and prospective field of application and limitations, particularly where centrifugal tube casting comes into competition with the piercing process. The main portion of the paper is devoted to the centrifugal casting of steel bars. According to the author, the importance of this process lies in its ability to produce a metal of better quality at a cost much lower than present methods. The mechanical and metallurgical features of the process are explained, and the machinery employed is described and illustrated. The mould used is similar in design to that employed for the casting of tubular shapes, except for the presence of partition lugs. In order to prevent these lugs from breaking up the metal into fine spray, the metal is teemed against a smooth-walled constricted neck of the mould where the metal takes up a spinning motion. A collar attached to the mould prevents the metal from running out, and it is thus forced down over a shoulder, gaining in centrifugal force on account of the increase in diameter. By the time it reaches the beginning of the partition lugs

it is spinning at the same rate as the partitions themselves. There is, therefore, no relative motion between the two, the metal generally flowing around the shoulders of the lugs and filling the spaces in between.

J. D. Capron, *Centrifugal Casting Processes* (Paper read before the American Iron and Steel Institute, May 1927). The paper opens with a summary of early developments in centrifugal casting, and describes the Delavaud process, the first to be used for the commercial production of iron castings on a large scale. The properties of pipes produced by this process are discussed, and brief particulars are included of other processes, including the "Sand Spun" or Mono-cast, the Hurst-Ball, and Henry-Weitling-Peake processes.

J. T. Mackenzie, *Cast-Iron Pipe Centrifugally made in Sand Moulds* (Paper read before the American Iron and Steel Institute, Oct. 1927). The sand-cast centrifugal process is briefly outlined, and the micro-structure and physical properties of the iron are described.

Malleable Castings.—M. Guedras, *Malleable Cast Iron* (Revue de Fonderie Moderne, 1927, vol. 21, Mar. 25, pp. 30–32). Reference is made to Réaumur's researches of 1722 and to Samuel's work in 1804, with some description of their methods for decarburising iron castings. In modern practice the carbon in the primary metal should exist in the combined form, cementite, and in that condition 3·2 to 3·4 per cent. carbon is not too high. Silicon must be kept low on account of its influence on the separation of graphite. For white malleable castings 0·5 per cent. silicon is suitable, while the manganese should be about 0·3 per cent. Sulphur must be kept as low as possible, not over 0·5 per cent., and phosphorus not over 0·225 per cent.

L. Thomas, *Progress in Foundry Practice since 1900* (Revue de Fonderie Moderne, 1927, vol. 21, Mar. 25, pp. 33–35). The author refers in particular to differences in European and American practice in the manufacture of malleable castings. Mention is made of the triplex process of the National Malleable Company in the United States, in which the annealing operation occupies five to six days instead of the usual seven to twelve. The composition of the raw material and properties of the finished casting are given, but other details are not stated.

M. Leroyer, *Malleable Castings* (Revue de Fonderie Moderne, 1927, vol. 21, May 10, pp. 101–111). The author outlines the development of the art of producing malleable iron castings, and describes the most recent practice in the manufacture of blackheart malleable castings in America, giving details of their tensile properties, with notes on the theory of graphitisation and the influence of elements on cast iron from the point of view of its suitability as a raw material for the production of malleable castings.

M. Leroyer, *The Decarburisation of Cast Iron* (Revue de Fonderie Moderne, 1927, vol. 21, June 10, pp. 149–153). The author discusses the

influence of time, temperature, character of ore, and thickness of castings on decarburisation.

Blackheart Malleable Castings (La Technique Moderne, 1927, Apr. 15, pp. 253-255). A general description of the process of the manufacture of blackheart malleable castings from white pig iron is given. The tensile properties of the finished material are stated.

D. Saito and H. Sawamura, *A New Phenomenon concerning the Graphitisation of White Cast Iron and its Application to the Manufacture of Blackheart Malleable Castings* (Memoirs of the College of Engineering, Kyōtō Imperial University, 1927, vol. 5, July, No. 1, pp. 1-59). The authors have found that a preliminary heat treatment of white cast iron followed by quenching greatly reduces the time of annealing in the manufacture of blackheart malleable cast iron. Malleable castings prepared in this manner are stronger but somewhat less malleable than those prepared by annealing white cast iron in the "as cast" condition.

L. E. Gilmore, *Proper Sulphur-Manganese Ratio must be Maintained* (Foundry, 1927, vol. 55, Sept. 15, pp. 734-735). The detrimental effect of sulphur and the importance of maintaining the correct sulphur-manganese ratio in malleable cast-iron melting are pointed out.

H. R. Hiscott, *The Manufacture of Malleable Iron Pipe Fittings* (Paper read before the Waverley Association of Gas Managers, June 24, 1927 : abstracts, Gas World, 1927, vol. 87, July 30, p. 110 ; Gas Journal, 1927, vol. 179, July 13, pp. 109-111). The author describes the manufacture of malleable iron fittings and discusses the properties of the material in relation to the use of the fittings for the conveyance of gas.

E. R. Taylor, *The Influence of Manganese and Manganese Sulphide on Whiteheart Malleable* (Paper read before the Institute of British Foundrymen : Foundry Trade Journal, 1927, vol. 36, July 7, pp. 23-24 ; July 14, pp. 41-44). From the result of tests it may be concluded that in whiteheart malleable the best mechanical results are obtained when the sulphur-manganese ratio is not greater than 1 to 2. When the ratio is much less than this good bend tests can be obtained, but the elongation appears to suffer. Metal containing excess manganese is strong without being ductile, and anneals to finely divided pearlite instead of ferrite. The presence of sulphide does not seriously affect the ductility of whiteheart malleable, and any harmful tendency is probably more than offset by the acceleration of the annealing due to the combined removal of both sulphur and manganese as sulphide. The results of the author's investigations of the influence of sulphur and manganese are also published in Iron and Steel Institute : Carnegie Scholarship Memoirs, 1925, vol. 14, pp. 131-161 ; 1926, vol. 15, pp. 381-406.

C. Kluijtmans, *Air-Furnace Practice* (Foundry Trade Journal, 1927, vol. 36, Sept. 1, pp. 197-198 ; Sept. 8, pp. 213-219). The subject is discussed under the following headings : Air-furnace design, compo-

sition of the charge, making the initial charge, oxidation of constituents, thickness of castings, influence of constituents on iron as cast, influence of constituents on annealing, melting practice, skimming off, taking a test plug, cooling of the test plugs, tapping blackheart malleable, and accidents to plant.

J. H. Hruska, *Better Boxes for Malleable Annealing* (Iron Age, 1927, vol. 120, Oct. 20, p. 1086). The life of cast-iron pots used for annealing malleable castings can be increased by higher carbon, silicon, and manganese in the metal. A further gain in the number of heats per box may be made by additions of up to 0.01 per cent. of aluminium and up to 0.40 per cent. of chrome to the molten pot metal.

R. Stotz, *Standardisation of Malleable Castings* (Giesserei Zeitung, 1927, vol. 24, July 15, pp. 385-392; Die Giesserei, 1927, vol. 14, May 28, pp. 356-358). A provisional standard specification, with comments thereon, for malleable cast iron is published. A definition of malleable cast iron is given, and the method of preparing test-bars, their dimensions, and the tensile properties are prescribed, and the limits of specific gravity, shrinkage, and hardness are specified.

Foundry Equipment.—F. G. Steinebach, *Mechanical Charger Feeds Three Cupolas* (Foundry, 1927, vol. 55, Aug. 1, pp. 599-603). A detailed illustrated account is given of the charging equipment at the Cleveland plant of the Westinghouse Electric and Manufacturing Co. The unit consists of a covered storage building with bins and a special scale car, and an electrically driven cupola charger which operates on a monorail track.

B. Finney, *Conveyor System Doubles Capacity* (Iron Age, 1927, vol. 120, Oct. 6, pp. 933-936). The author describes and illustrates the conveyor system for the handling of castings and other materials in operation at the foundry of the Monitor Furnace Co., Cincinnati.

The Works of R. B. Tennent, Ltd., Whifflet Foundry (Foundry Trade Journal, 1927, vol. 36, Sept. 29, pp. 289-290). A brief illustrated account is given of the equipment of this foundry where steel rolls and other castings are produced.

Handling and Melting Grey Iron (Iron Age, 1927, vol. 119, June 2, pp. 1587-1590). The new grey iron foundry of the Maytag Co., Newton, Iowa, is described and illustrated. Two-standard Whiting continuous melting cupolas are used, and by careful control it has been found possible to melt $14\frac{1}{2}$ lb. of iron per lb. of coke. The pig iron is handled by two magnets on a single lifting crane. Both magnets can be operated independently by one cranesman.

E. Bremer, *Preheating Reduces Melting Period* (Foundry, 1927, vol. 55, Aug. 15, pp. 626-630). *Electric Annealing Furnace is Controlled Automatically* (Sept. 1, pp. 674-677). These two articles describe the layout and equipment of the plant of the Burnside Steel Foundry Co., Chicago. The melting of metal and also the annealing of castings is carried out in electric furnaces. The melting furnaces are of the

multiple type mounted in pairs on a turntable with one set of electrodes common to both furnaces.

V. Delport, *French Automobile Foundry Employs Continuous System* (Foundry, 1927, vol. 55, Oct. 1, pp. 748-750, 752-755). A general illustrated description of the grey iron and malleable iron foundries at the Citroen Works, near Paris.

P. Dwyer, *Stepping Up Production Mechanically* (Foundry, 1927, vol. 55, July 15, pp. 550-554, 574; Aug. 1, pp. 588-592; Aug. 15, pp. 635-638). A series of articles describing the methods and equipment employed at one of the Buffalo plants of the American Radiator Co. The first article deals with the core room, the second with the sand-handling and conveying equipment in the moulding department, and the third with the methods and equipment for cleaning and handling the castings.

PRODUCTION OF STEEL.

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I.—PROCESSES OF STEEL PRODUCTION.

Bessemer and Open-Hearth Processes.—Ch. Gonner, *On the Present State of the Basic Bessemer Process* (Revue Technique Luxembourgeoise 1927, June (Special Number), pp. 28–41). The author deals with the following aspects of the subject: General considerations on the evolution of the basic Bessemer process, management of the process, influence of the chemical composition and of the physical qualities of the pig iron, mixers, shape and dimensions of converters, blast mains, use of oxygen-enriched air, addition of deoxidisers in the liquid state, melting furnaces, pouring, the dolomite shop, tar, and the solubility of basic Bessemer slags.

J. Seigle, *Qualities and Conditions of Usage of Basic Bessemer Steels, particularly for Railway Rails* (Revue Technique Luxembourgeoise, 1927, vol. 19, No. 4, pp. 83–99). The author gives details of the manufacture of a large variety of types of basic Bessemer steel, and discusses the various qualities and properties of basic Bessemer and open-hearth steels. He then discusses steel rails, in particular, alterations of the metal in service, the cracking of rails obtained from different sources, faults in rails due to the steel and their prevention, quenched rails, &c. He gives statistics of accidents due to rail failure, describes the production of rail steel ingots, and gives some particulars of specifications from various countries.

E. Faust, *Relations between the Slagging of Iron and of Manganese in the Basic Bessemer Process* (Archiv für das Eisenhüttenwesen, 1927, vol. 1, Aug., pp. 119–126). Tests showed that there is a relation between the MnFe ratio in the slag and the MnFe ratio in the bath in basic Bessemer practice. It can be deduced from this result that the proportion of manganese slagged, compared with the total manganese present, is in a definite ratio to the proportion of iron slagged compared with the total iron. These relations were found to exist in the acid Bessemer process also, but the constant of the equation is different. The possibility of applying the relation to the open-hearth and other metallurgical processes is indicated.

C. S. Nugent, *Open-Hearth Furnace, Past and Present* (Blast-Furnace and Steel Plant, 1927, vol. 15, May, pp. 225-226). A brief review of the development of the open-hearth furnace, from Réaumur's attempts in 1722 to make steel on the breast of an open-hearth furnace with a mixture of cast iron and wrought iron up to the present day, is given, followed by notes on the construction and operating features of a modern furnace.

C. W. Veach, *Discuss Open-Hearth Furnace Problems* (Blast-Furnace and Steel Plant, 1927, vol. 15, June, pp. 278-279). A meeting of open-hearth superintendents was held in Buffalo, N.Y., on May 3-5, for the discussion of practical matters concerning the basic open-hearth process. The author of this article summarises the opinions expressed under twelve heads; the topics were: sloping back walls (considered to be advantageous), suspended roof (good but expensive), types and method of laying checker bricks (important in controlling furnace economics), effect of waste-heat boilers on furnace operation (usually good; where not so, the induction fan was generally at fault), size of brick for open-hearth roof, silica brick in checker chambers (not in wide use, but highly efficient), dolomite gun (labour and time saver, and places material accurately without scattering), size of nozzle and sleeve, furnace yield (average yields quoted ran from 84 to 92 per cent.), the low pig iron percentage and high limit for quality steel, limestone *versus* burnt lime (limestone generally considered better; the CO_2 evolved during calcination causes turbulence, so eliminating slag inclusions), and pig iron research.

C. W. Veach, *Making Basic Open-Hearth Steel* (Blast-Furnace and Steel Plant, 1927, vol. 15, July, pp. 323-325). The author discusses several features in the manufacture of basic open-hearth steel, such as furnace construction, operation, charging, and heat control.

W. Trinks, *Combustion in the Open-Hearth Furnace* (Fuels and Furnaces, 1927, vol. 5, Apr., pp. 477-482). The author discusses the heat requirements of open-hearth furnaces, the character of flame to secure the best results, and various combustion devices.

C. Schwarz, *Contribution to the Calculation of the Useful Heat in Open-Hearth Charges* (Archiv für das Eisenhüttenwesen, 1927, vol. 1, July, pp. 33-40). After a careful definition of the "useful heat" in a cyclic process, the data available for use in metallurgical literature and calculations are collected and criticised, with a view to providing a clear outline of the position for future work. Useful tables are given of the total heat, heat of fusion, and melting points of various slags and minerals, grey iron, 80 per cent. ferro-manganese, and pure iron. The heats of various reactions are also tabulated.

G. Neumann, *Thermal Trials on an Open-Hearth Furnace* (Archiv für das Eisenhüttenwesen, 1927, vol. 1, Aug., pp. 111-118). Tests were carried out by means of gas analysis on the conditions of combustion in the hearth of a 40-ton tilting open-hearth furnace. Suggestions are made as to improvements. Results showing the alteration

in gas composition in the regenerators are given, and also the temperature conditions in the checkers, and deductions are made as to the consequent effect on gas flow in the checkers.

C. Schwarz, *The Heat Balance of the Open-Hearth Furnace, with Special Reference to Waste Gas Losses* (Archiv für das Eisenhüttenwesen, 1927, vol. 1, Oct., pp. 273-283). The useful heat is calculated from published balances, and the figure of 30 to 40 per cent. loss in waste gases is almost general, as is the absolute value 600-700 kg. cal. per ton of steel. The separate items of the heat balance are then critically examined, and reference is made to the incomplete nature of the Sankey diagram, mainly due to the fact that temperatures are not shown. A heat-flow diagram, with temperatures added, is given. It is shown that, even after using the heat drop of the waste gases to the utmost for preheating purposes, sufficient waste heat at a high enough temperature for waste-heat boilers remains if the losses between hearth and chimney can be correspondingly reduced.

E. Damour, *The Thermal Balance-Sheet* (Chaleur et Industrie, 1927, vol. 8, May, pp. 255-265). The author discusses thermal balance-sheets, their preparation and uses, exemplifying his remarks by a balance-sheet for an open-hearth furnace.

V. Polak, *Tests to Determine Degrees of Radiation in Open-Hearth Furnaces* (Zeitschrift für Technische Physik, 1927, vol. 8, pp. 71-74). The importance of radiation of flue-gases in heat transmission in open-hearth furnaces, nature of gas radiation, and results of radiation measurements are dealt with.

P. Oberhoffer and H. Schenck, *Theoretical and Practical Investigations on the Deoxidation of Iron with Manganese* (Stahl und Eisen, 1927, vol. 47, Sept. 15, pp. 1526-1536). Increased attention is being directed to oxygen in steel. The oxygen is most probably present as ferrous oxide, unless other elements are present. Oberhoffer and Ammann have recently shown that a considerable part of the oxygen in solid steel exists as silica and alumina, but whether these materials are dissolved or suspended in liquid steel cannot yet be stated. It should be noted that the oxygen, determined analytically in steel, is not only present in the form of ferrous oxide, but that all alloying elements can participate in the formation of oxides, which again may unite together and give rise to complex compounds. Further, the influence of oxygen on steel can vary with the form in which it exists. The behaviour of sulphur is somewhat analogous—*i.e.* its deleterious influence may be reduced by the addition of manganese. A complete solution of the question stands or falls with the possibility of carrying out accurate determinations of each separate oxide. Silica and alumina can now be determined with fair accuracy by examination of the insolubles after bromine extraction, but iron and manganese oxides cannot, although total oxygen can be accurately determined by hot extraction. The process of deoxidation can be followed quantitatively so far as the

reduction of oxygen in the bath is concerned, which is the first object of deoxidising additions. Deoxidation in practice has shown that complete removal of oxygen is only possible by extraordinary measures, such as the treatment *in vacuo* of material containing carbon; otherwise, the metal always contains a certain proportion of oxygen; the progress of the deoxidation reactions is limited by conditions of equilibria. Le Chatelier, Styri, and McCance have all attempted to determine the equilibrium conditions of the $\text{FeO} + \text{Mn} \rightleftharpoons \text{MnO} + \text{Fe}$ at 1600°C. are given. Schenck considers that the absolute values of their isotherms must be discounted, because, first, they are based on data referring to the crystalline state, and no account is taken of discontinuities in passing from crystalline to liquid; secondly, it seems doubtful if the relation between the reaction pressures of manganese and of iron oxide and their concentration can be expressed by one constant over the whole range of manganese concentration; finally it is assumed in these calculations that manganese oxide is practically insoluble in pure iron. Although this has never been the subject of a direct trial, evidence is forthcoming from various sources that the concentration of MnO in commercial iron cannot be neglected. The equation must be of the type
$$\frac{[\text{FeO}][\text{Mn}]}{[\text{MnO}]} = K_2,$$

which no longer says anything about total oxygen, but only determines the ratio of the compounds FeO and MnO in the bath, and shows that MnO increases with increasing manganese. If the law of partition holds for the distribution of manganese and ferrous oxides between slag and bath, further relations are forthcoming, from which eventually there results an equation with the unknowns, which can be solved from the results of the tests. A series of three vacuum furnaces were set up, and attempts were made to determine equilibria from both sides of the equation $\text{FeO} + \text{Mn} \rightleftharpoons \text{MnO} + \text{Fe}$; but, on account of the volatilisation of metallic manganese, great difficulties were experienced. Electrolytic iron was melted *in vacuo* and cooled. The regulus was then heated, with addition of magnetic oxide, to 1600° and manganese was added; equilibrium was assumed after five minutes. In oxidising iron with MnO great difficulties were experienced due to the crucibles being attacked. The cold reguli were analysed for total oxygen and manganese. The results are plotted in a curve of hyperbolic form. Slags were analysed in five cases, and curves drawn up for the MnO/FeO ratio in the deoxidation products, and MnO in the slag was plotted against Mn per cent. in the bath. An attempt to use the data to determine the equilibrium constant failed, as a negative result was obtained; it may be that the equilibrium constant is not a function of temperature only, but also of the ferrous oxide content of the bath, and, further, the figure for total oxygen may be incorrect on account of the oxides present in the apparatus, rendering impossible the determination of a certain fraction of the oxygen; at the same time, it gives promise of enabling a determination of the equilibrium constant to be made if a vessel with

no trace of oxide is used for the oxygen determination. Trials are in hand along these lines.

H. D. Hibbard, *Parallel between Sulphur and Oxygen in Steel Metallurgy* (Fuels and Furnaces, 1927, vol. 5, Nov., pp. 1445-1447). A brief discussion is given of the action of sulphur and oxygen in the manufacture of steel.

R. Hennecke, *The Scrap Carburising Process* (Stahl und Eisen, 1927, vol. 47, May 12, pp. 777-780). The manufacture of steel from scrap in the open-hearth without the use of any pig iron whatsoever is described. For two years a 56-ton open-hearth has been operated for this scrap process, the charge consisting of about 54 tons of steel and iron scrap, including $7\frac{1}{2}$ tons of steel turnings. The additions consisted of lime 32 cwt., anthracite 24 cwt., ferro-manganese 7 cwt., fluorspar 5 cwt., and of further lime 20 cwt. The total time of the heat, including melting down, was 10 hrs. 15 mins. The finished steel contained carbon 0.1, manganese 0.42, sulphur 0.045, phosphorus 0.02 per cent. The melting operations are fully described, and the process proves highly economical for a steelworks, not combined with blast-furnaces, where liquid pig cannot be charged into the steel furnaces.

E. Killing, *The Pig and Ore Process, with Preliminary Refining* (Stahl und Eisen, 1927, vol. 47, July 21, pp. 1197-1208). This paper deals with the process as carried out at the works of the Bochumer Verein, which is similar to that carried out during 1910-12 at the Georgsmarienhütte. The plant consists of two tilting open-hearth furnaces of 250 tons capacity, acting as refining furnaces, and six stationary 56-58-ton furnaces. The process has been subjected to simultaneous metallurgical and thermal investigations. The disadvantages of a high carbon content in the pig iron, which increases the endothermic and thermal losses, are confirmed. A method of working a suitable iron is shown, and means of avoiding the loss of flame through the doors and utilising the heat in the waste gas are indicated. It can be seen from the records of the furnace working that, for the process tested, the output per sq. m. of hearth surface per hour, the coal consumption, and working costs are more favourable than those of the usual scrap process, and are certainly as good as the ordinary open-hearth process with cold charges as far as total manufacturing costs are concerned. The greatest influence on total cost appears to be the margin between the cost of pig iron and scrap.

C. H. Herty, jun., *Burnt Lime and Raw Limestone in the Basic Open-Hearth Process* (Industrial and Engineering Chemistry, 1927, vol. 19, May, pp. 592-594). The use of burnt lime in the open-hearth furnace has the advantage of decreasing the heating period; it is, however, somewhat restricted to low hot-metal charges and by an economic balance between the speed of heating, the yield of iron, the cost of pig iron and scrap, the cost of burnt lime and limestone, and the depreciation of an open-hearth furnace using a high and a low hot-metal charge. The qualities of the burnt lime and limestone are of

prime importance; sulphur, silica, magnesia, and carbon dioxide should be as low as possible in burnt lime, and all these, except CO_2 , should be lower in limestone than in burnt lime.

K. von Kerpely, *Manufacture of Silicon Structural Steel in the Bosshardt Furnace* (Centralblatt der Hütten- und Walzwerke, 1927, p. 367; Stahl und Eisen, 1927, vol. 47, Aug. 11, pp. 1332-1333). The author reports the results of an investigation of six charges of silicon steel made in a 10-ton Bosshardt furnace. The average composition of the metal was carbon 0.13, silicon 1.05, and manganese 0.78 per cent. The product showed tensile properties as follows:

Elastic Limit. Kg./sq. mm.	Yield Point. Kg./sq. mm.	Elongation. %	Reduction of Area. %
44.5	56.4	24.2	64
39.8	53.8	25.8	67

Manufacture of High-Silicon Steel for Structural Purposes in the Open-Hearth (Stahl und Eisen, 1927, vol. 47, May 26, pp. 876-881). Correspondence on the question of the quality of silicon steel is published. K. von Kerpely points out that the silicon steel made in a 10-ton Bosshardt furnace is much more homogeneous and reliable than such steel made in an 80-ton open-hearth furnace. J. Meiser, who has lately published results obtained in the production of silicon steel at the Dortmunder Union in a large open-hearth furnace, maintains that his product is in no respect inferior to that made in a Bosshardt furnace. Both parties give particulars of chemical composition and tensile tests.

F. Jansen, *The Fracture Test in Steel-Making* (Archiv für das Eisenhüttenwesen, 1927, vol. 1, Aug., pp. 147-155). Fracture tests can be applied with successful results in almost all melting processes. The most important and commonest of such tests, those for phosphorus and carbon, are described with their distinguishing characteristics. The extensive use of these tests, in addition to rapid chemical tests, in steelworks, is explained by their simplicity. They are chiefly of use in forming an opinion on the progress of a charge. It was further shown that red-shortness is not dependent alone on the quantity of oxygen which is present, but that it occurs when the oxygen content is so high that the manganese present is insufficient to unite with all the oxygen to form MnO . The greater the excess oxygen, the more marked the red-shortness and the larger the grain, as may be established metallographically. The influence of temperature on red-shortness was investigated for the range 700° to 1205° , and red-shortness was found most marked at 1025° .

M. Hamasumi, *Estimations of Carbon Based on the Fracture* (Archiv für das Eisenhüttenwesen, 1927, vol. 1, Aug., pp. 157-160). The general points in estimating the percentage of carbon from the fracture are considered, and the basis of the differentiation is discussed, with the assistance of photomicrographs. Manganese, as a consequence of the displacement of the eutectoid, is equivalent to an increase in carbon, so that its influence must be kept in mind in these determinations.

V. Löf, *Steel Melting* (Jernkontorets Annaler, 1927, vol. 111, pp. 257-262). The author describes the manufacture of low-carbon steel at Domnarfvet, Sweden.

A. L. Foell, *Flat Suspended Open-Hearth Roof* (Paper read before the Association of Iron and Steel Electrical Engineers: Iron Age, 1927, vol. 119, June 23, pp. 1814-1815). Particulars are given of the experiments conducted at the plant of the Donner Steel Co., Buffalo, in the use of flat suspended roofs for open-hearth furnaces. This type of roof is found to have a much greater life than the spring arch type. The author is of the opinion that the higher first cost is counterbalanced by lower maintenance cost.

Suspended Refractory Brick Roof for Furnaces and Fireboxes on the Borne-Bonet System (Génie Civil, 1927, vol. 91, Oct. 22, p. 414). The bricks, trapezoidal in cross-section, are hung on rings which in turn hang from rods fastened between girders. The shape of the bricks permits their use on curves; on flat surfaces the wedge-shaped spaces between them are filled, after assembly, with powdered refractory material.

F. H. Loftus, *Open-Hearth Furnace Regenerators* (Iron Age, 1927, vol. 120, July 7, pp. 10-12; Blast-Furnace and Steel Plant, 1927, vol. 15, Sept., pp. 438-440). The author discusses the factors governing the design of checker brick for proper passages, heat absorption, and strength, and puts forward a type of checker brick designed for maximum absorption of heat and minimum obstruction to the flow of gases.

W. H. Fitch, *Recuperators Applied to Open-Hearth Furnaces* (Proceedings of the Engineers' Society of Western Pennsylvania, 1927, vol. 42, Jan., pp. 506-517; Blast-Furnace and Steel Plant, 1927, vol. 15, Apr., pp. 186-188). The advantages of adding a recuperator to the regenerators of an open-hearth furnace are discussed, and drawings of such an arrangement are given. The use of "core-busters" is described; these are solid cylinders of fireclay fitted with short legs, and are placed inside the tubes of the recuperator to compel the air to pass in close contact with the tube walls.

A. E. Perkins, *Binding for Industrial Furnaces* (Mechanical World, March 11, 1927; Blast-Furnace and Steel Plant, 1927, vol. 15, June, pp. 282-283; Forging, Stamping, Heat Treating, 1927, vol. 13, Aug., pp. 329-330). The author gives the calculations required to indicate the strength necessary in the buckstays and tie rods used for binding furnaces. The life of a furnace is largely dependent upon the provision of suitable binding and of means of adjustment to allow for expansion and contraction during heating up and cooling down.

W. Trinks, *Use of Water-Cooling in Open-Hearth Furnaces* (Fuels and Furnaces, 1927, vol. 5, May, pp. 585-586).

M. Pavloff, *Dimensions of Open-Hearth Furnaces of 100 Tons Capacity* (Stahl und Eisen, 1927, vol. 47, June 9, pp. 953-955). Tables are given of the principal dimensions of 100-ton open-hearth furnaces;

the data are calculated by the author and compared with dimensions adopted as standard in America, and with those of other countries.

J. D. Knox, *Basic Open-Hearth Steel Industry Embraces 960 Furnaces* (Iron Trade Review, 1927, vol. 81, Sept. 29, pp. 773-777). Tables are given showing the location, number, and capacity of basic open-hearth furnaces in the United States by districts and by plants. The number and capacity of Bessemer converters are also given.

Electric Steel Furnace Practice.—G. Bulle, *Electric Heating in the Iron and Steel Industry* (Archiv für das Eisenhüttenwesen, 1927, vol. 1, Sept., pp. 205-224; Oct., pp. 313-324). A general review of the present position with regard to the application of electric heating in the iron industry generally, including blast-furnaces, steel furnaces, reheating furnaces, soaking pits, and annealing furnaces, galvanising, enamelling, and foundry work. Types of furnaces, such as the arc, the induction, and the resistance furnace, together with their equipment and electrical conditions, receive consideration, and also the factors which may determine the choice of type. Costs of electric furnace operation are gone into in detail.

F. Knoops, *Determination of the Cost of Electric Power, with Special Reference to Electric Melting* (Centralblatt der Hütten- und Walzwerke, 1927, vol. 31, May 4, pp. 225-230).

E. Houdremont and H. Kallen, *On Steel for Ball Races* (Zeitschrift des Vereines Deutscher Ingenieure, 1926, vol. 70, July 31, pp. 1035-1039; *abstract*, Metallurgist, 1927, June 24, p. 83). The preparation and properties of ball-bearing steels, their structure, and possible defects in their production, are dealt with. The steels are usually prepared in an open-hearth or electric furnace, the basic electric being preferable to the basic open-hearth; crucible steel is ruled out on account of the price. Pure scrap or Swedish charcoal iron are the most suitable raw materials. The addition of chromium has many advantageous effects: the hardness and elastic limit are raised, the carbide particles are smaller, more numerous and better distributed, and the necessary heat treatment is rendered easier and less drastic. The pouring of the ingots, the rolling temperature, and the hardening temperature are points requiring care. Usually ball races are cut from drawn tubes, but recently forged races have been tried.

F. W. Manker, *The Manufacture and Heat Treatment of Roller Bearings* (Fuels and Furnaces, 1927, vol. 5, Apr., pp. 443-446). An account is given of the practice of the Timken Roller Bearing Company in the manufacture of roller bearings. The formation of the various parts and methods of heat-treating are noted.

K. v. Kerpely, *The Oxidation Process in Arc Furnaces* (Centralblatt der Hütten- und Walzwerke, 1927, vol. 31, Aug. 24, pp. 471-475). The author discusses the chemistry of the arc furnace process and its effect upon manganese, phosphorus, silicon, and constituents of iron ore.

Steel Plant Uses Electric Furnaces (Iron Age, 1927, vol. 119, June 9, pp. 1665-1667, 1714; Iron Trade Review, 1927, vol. 80, June 9, pp. 1467-1469). The steel-making plant of the Timken Roller Bearing Co., at Canton, Ohio, is described and illustrated. The equipment includes two 25-ton and one 7-ton 3-phase arc furnaces, and one 100-ton open-hearth furnace. Two noteworthy features of the equipment are the use of a ladle crane equipped with worm drive, and a new type of worm-driven charger.

D. F. Campbell, *High-Frequency Induction Melting* (Paper read before the Iron and Steel Institute, Sept. 1927: this Journal, p. 103).

W. Steinhaus and A. Kussmann, *High-Frequency Furnaces for Small Charges* (Zeitschrift für Metallkunde, 1927, vol. 19, Sept., pp. 346-348). The high-frequency induction furnace was used in German metal research laboratories only at isolated places at first, although it offered great advantages for the production of small experimental melts. Experiments were carried out with the most widely varying sources of H.-F. current, in order to discover the most suitable furnace for charges of from 20 to 100 grm. The most suitable was found to be a damped oscillatory circuit with a rotating spark-gap. The arrangement and dimensions for a 6-kw. furnace are given.

M. Fourment, *Present State of the Problem of Melting Alloys* (Revue de Métallurgie, Mémoires, 1927, vol. 24, Apr., pp. 179-193). A description and discussion of electric furnaces of various types—arc, resistance, L.-F. and H.-F. furnaces.

C. H. Stevenson, *The Trend of the Electric Furnace Design* (Forging, Stamping, Heat Treating, 1927, vol. 13, June, pp. 222-224). The author reviews the evolution of the modern electric furnace from the combustion type, and gives reasons for the present trend in design.

G. I. Finch, *Some Industrial Applications of Electrothermics* (Journal of the Royal Society of Arts, 1927, vol. 47, Sept. 30, pp. 1081-1107; Oct. 7, pp. 1108-1128; Oct. 14, pp. 1132-1151). The principles of the conversion of electrical energy into heat are discussed, and the electrothermics of the fixation of nitrogen and of the melting and refining of steel are fully dealt with. Under the last heading the electrical equipment of all the electric furnaces which have been or are being used by steelmakers is described.

J. D. Keller, *Auxiliary Equipment for Electric Melting Furnaces* (Fuels and Furnaces, 1927, vol. 5, Aug., pp. 1011-1017). The author discusses various apparatus employed for controlling arc and induction furnaces. Electrical connections, electrode regulators, power limitators, reactors, transformers, and generators are dealt with.

Theories of Electric Arc Furnaces (Centralblatt der Hütten- und Walzwerke, 1927, vol. 31, Jan., pp. 37-38).

R. Catani, *The Calculation of Electric Furnace Circuits* (Paper read before the American Electrochemical Society, Sept. 1927). In the first part of the paper furnaces with one circuit only are considered:

(1) Apparent maximum power; (2) maximum absorbed power; (3) resistances—lead resistance, electrode resistance, and arc resistance; (4) reactances; (5) efficiency—formulae for efficiency and power; (6) calculations from efficiency and from voltage. In the second part of the paper furnaces with several circuits are discussed: (1) Mutual induction; (2) correct disposition of circuits.

H. J. Miller and M. Lindeman, *Behaviour of Molybdenum as Resistor in the Electric Furnace* (American Institute of Mining and Metallurgical Engineers, 1927, Technical Publication No. 16). The destruction of molybdenum ribbons used as resistors in electric furnaces is due chiefly to chemical reaction with materials present in heating tubing, insulation, or gases in the furnace. Of those materials most likely to be present, silica and carbon are the most destructive. For the best working conditions of such furnaces it is recommended that: (1) Both heating tubing and insulation should be of calcined pure alumina, mixed with aluminium hydroxide as binder and fired at 1500° C. (2) The first heating of a new furnace should be carried out under high hydrogen pressure, which may be later reduced. (3) If the material used for heating tubing or insulation contains carbon, oxides of a high degree of oxidation should be added, so that they may react with it, the products of the reaction to be removed by evacuation. (4) The molybdenum ribbon may be coated with molybdenum oxides having a low degree of oxidation to protect it from forming oxides or carbides.

Steelworks Plant and Equipment.—*Iron and Steel Works in Glasgow District* (Iron and Coal Trades Review, 1927, vol. 115, Sept. 23, pp. 447–457). Illustrated particulars are given of the equipment of the following works: Clydebridge Works of David Colville & Sons, Ltd.; Eclipse Works of Frederick Braby & Co., Ltd.; Blochairn Works of the Steel Company of Scotland, Ltd.; Mossend Works of William Beardmore & Co., Ltd.; Clydesdale Works of Stewarts and Lloyds, Ltd.; Wishaw Works of the Glasgow Iron and Steel Co., Ltd.; Gartcosh Works of Smith and McLean, Ltd.; Union Works of the Scottish Tube Co., Ltd.; Waverley and Northburn Works of the Scottish Iron and Steel Co., Ltd.; Whifflet Works of William Bain & Co., Ltd.; Whifflet Foundry of R. B. Tennent, Ltd.; Renfrew Works of Babcock and Wilcox, Ltd.; and the works of Mavor and Coulson, Ltd.

The Works of David Colville & Sons, Ltd., Clydebridge Steelworks (Foundry Trade Journal, 1927, vol. 37, Oct. 13, pp. 35–36). Illustrated particulars are given of the melting shop and rolling-mills at this plant.

Famous British Works (Iron and Steel Industry, 1927, vol. 1, June 3, pp. 59–64; Nov., pp. 51–54). A series of articles describing various works in the United Kingdom. The present papers deal with the works of Messrs. David Colville & Sons, Ltd., and Messrs. Edgar Allen & Co., Ltd., Sheffield. For the first two articles in the series see *abstract*, Journ. I. and S.I., 1927, No. I. p. 869.

Vereinigte Stahlwerke A.G. Düsseldorf (Iron and Coal Trades Review, 1927, vol. 115, Sept. 2, pp. 325-328; Sept. 9, pp. 359-362). Particulars are given of the many interests controlled by the Vereinigte Stahlwerke A.G., which represents the commercial alliance of four very important groups of works: The Rhein-Elbe Union, the Thyssen Group, the Phœnix Group, and the Rheinische Stahlwerke. The company owns 48 collieries, 35 iron ore mines, in addition to important holdings in the Siegerland, in the Lahn and Dill district, in the Harz, Bavaria, Sweden, Spain, and Brazil. The company also owns limestone and dolomite quarries and clay and quartzite mines. The iron and steel works controlled by the company comprise 19 blast-furnace plants, with a total of 70 blast-furnaces. The steelworks comprise 39 basic Bessemer converters and 124 open-hearth furnaces, the annual output capacity of the steelworks being about 9 million tons of ingots. Descriptions of the following works are given: Hütte Ruhrort-Meiderich, Abteilung Bochumer Verein, Abteilung Dinslaken, and the August Thyssen Hütte at Hamborn. Brief descriptions are also included of other plants owned by the company.

Citric Solubility of Basic Slags.—T. Dunkel, *The Citric Acid Solubility of the Phosphoric Acid in Basic Bessemer Slag* (Stahl und Eisen, 1927, vol. 47, July 21, pp. 1205-1207). The silica necessary to raise the citric acid solubility of basic Bessemer slags was previously provided by silicon oxidised from the iron. But, on economic grounds, the silicon in pig iron has recently been reduced, and the Ruhrort Steelworks of the Phœnix Co. has carried out tests to determine if the rate of cooling the slag influences the solubility, how much silica must be added to the slag, and in what manner, to obtain maximum solubility of the slag. It was concluded that no attention need be paid to the rate of cooling. It is well known that by adding silica to the basic slag the citric solubility of the phosphoric acid of the slag can be considerably increased. Blome (Stahl und Eisen, 1910, vol. 30, p. 2161) considers that silica should be added in sufficient quantity to produce the compound $(\text{CaO})_5 \cdot \text{P}_2\text{O}_5 \cdot \text{SiO}_2$, according to which formula every 1 per cent. P_2O_5 requires $0\cdot425$ per cent. SiO_2 , and this figure $0\cdot425$ he terms the factor of siliconisation. Very vigorous agitation of the bath is necessary to produce a thorough mixing of the silica with the slag, but there is no stirrer which can improve on the agitation caused by the passage of the blast through the metal, as a means for the mixing of the reagent. The author's trials aimed at finding out if a siliconising factor of $0\cdot425$ was really necessary to attain the maximum citric solubility, and his results show that the solubility remains exactly the same with a factor of $0\cdot315 \text{ SiO}_2$. Below this limit the solubility falls rapidly. The most favourable moment for adding the silica with the lime is between the end of the carbon removal and the beginning of the after-blow. The addition should be in the form of lumps of about fist size. Old silica brick linings broken up will serve admirably.

II.—CASTING AND TREATMENT OF INGOTS.

Segregation and Inclusions in Steel Ingots.—A. Wimmer, *The Macro- and Microstructure of Blowhole Segregations* (Stahl und Eisen, 1927, vol. 47, May 12, pp. 781–785). A discussion of the origin and mode of formation of gas blowholes in steel, and of the chemical composition of such spots in the metal, particularly with regard to their enrichment in phosphorus, sulphur, and oxygen. The macro- and microstructure as revealed by different etching methods are considered in detail, some light being thrown on the mutual behaviour of ferrite, carbon, and phosphorus during the secondary crystallisation. Based on observations of the distribution and arrangement of the slag inclusions, a diagram of the sequence of crystallisation of iron, iron sulphide, and iron oxide in the ternary system has been drawn.

v. Göler and G. Sachs, *The Genesis of the Structure of Cast Ingots* (Zeitschrift des Vereines Deutscher Ingenieure, 1927, vol. 71, Sept. 24, pp. 1353–1357). The crystalline structure of metal castings is actually a problem of heat conductivity. Macroprints of sections of cast metals show the crystal growth proceeding at right angles from the walls of the mould, and the manner in which the form of crystal growth is modified by changing the form of the mould, and the effect of this upon piping and segregation of impurities, are illustrated and discussed. For the experiments zinc was used, which was cast in small ingots in moulds of rectangular and polygonal form with more or less curved (or fluted) sides.

A. C. Fieldner, *Co-operative Research in Ferrous Metallurgy and the Problem of Inclusions in Steel* (Proceedings of the Engineers' Society of Western Pennsylvania, 1927, vol. 43, June, pp. 221–242). The programme of research on inclusions in steel and their elimination to be undertaken co-operatively by the U.S. Bureau of Mines, the Carnegie Institute of Technology, and the Metallurgical Advisory Board is given. The organisation of the research and the facilities available for carrying it out are described.

C. H. Herty, jun., *Fundamental Research in Steel Manufacture* (Transactions of the American Society for Steel Treating, 1927, vol. 11, June, pp. 899–914, 1015). A classification is given of the problems encountered in the making of steel, the paper being restricted to a discussion of the fundamental research which deals with slag-metal reactions, with particular reference to the formation and elimination of non-metallic inclusions, formed from manganese, silicon, and aluminium. In order to attack the problem of solid non-metallic inclusions in steel, it is necessary to work along two lines—namely, (1) the effect of inclusions on the rolling and service quality of steels, with particular regard to the amount and type of the inclusion present; and (2) the formation and elimination of inclusions.

J. D. Gat, *Physical and Chemical Structure of Ingots* (Blast-Furnace and Steel Plant, 1927, vol. 15, May, pp. 207–211). Defects in ingots,

such as piping, segregation, liquation, banding, and porosity, are considered from the metallurgical point of view, and their formation is studied.

H. D. Hibbard, *Use of Poisons in Wrought Iron and Steel* (Fuels and Furnaces, 1927, vol. 5, Sept., pp. 1175-1180 ; Oct., pp. 1333-1334, 1340). A poison is defined by the author as a constituent which effects more harm than its proportion as a non-ferrous ingredient would account for. The advantages and disadvantages of certain amounts of sulphur, phosphorus, and oxygen in Bessemer and open-hearth steels are discussed. The effect of oxides on basic Bessemer steel and the influence of phosphorus on wrought iron are also dealt with.

C. Benedicks and H. Löfquist, *Our Present Knowledge regarding Non-Metallic Inclusions in Iron and Steel* (Paper read before the International Testing Congress, Amsterdam, 1927).

H.-G. Vosgien, *The Influence of the Average Manganese Contents of the Furnace Charges and of the Silicon Contents of the Finished Metal on the Manufacture of Wheel Tyres* (Arts et Métiers, 1927, vol. 80, Aug., pp. 289-294). In the manufacture of tyres (the methods of casting the ingots and forging the tyres are described) trouble was experienced with cracks and fissures. The composition of the steel was : C 0.420, Mn 0.98, Si 0.30 per cent. ; the tensile strength was 70 kg. per sq. mm., and the elongation on 200 mm. 15 per cent. The faults found during forging were—(a) superficial cracks, due to slag inclusions or small blowholes ; and (b) more or less deep fissures inside the hole and on the plane surface of the ring, corresponding to the head of the ingot, due to pipe. After an exhaustive investigation it was proved that the trouble diminished when the manganese was as high as possible (never less than 0.8 per cent.), and when the silicon content was held at such a figure that the metal was just killed ; any departure from that optimum silicon content had an adverse effect.

W. S. Wilson, *The Control of Piping in Steel Ingots* (Iron and Steel of Canada, 1927, vol. 10, Aug., pp. 231-233, 235). A review of the effects on piping and segregation which result from the use of various shapes of moulds, hot tops, and other means that are used to try to suppress these phenomena.

FORGING AND ROLLING-MILL PRACTICE.

Reheating Furnaces.—V. Bouchet, *The Importance of Soaking Pits as Intermediate Plant between the Steelworks and the Rolling-Mills* (Revue Technique Luxembourgeoise, 1927, vol. 19, No. 1, pp. 1-8). The author examines the relationship of the rolling-mills to the steelworks, and establishes rules for the economic organisation of the working of the soaking pits. He also discusses the necessity for uniform heating of the ingots in the pits, the cleaning of the pits, and the nature of the slags formed.

Soaking Pit Built with Recuperators (Iron Age, 1927, vol. 119, June 23, pp. 1811-1812). *Soaking Pit with Recuperator* (Blast-Furnace and Steel Plant, 1927, vol. 15, July, pp. 347-349, 355). The soaking pit described has the firing and exhaust ports located in the same end wall. Since the firing port is above the top of the ingots, the gases, it is claimed, are well mixed before coming into contact with the steel. The pit is 5 ft. 6 in. wide by 9 ft. 6 in. long, and holds six 21½ in. square ingots, of about 7800 lb. each. In designing the pit care was taken to make the recuperator large enough to supply the air at all times at a pressure sufficient to maintain a positive pressure in the pit. A slag pocket is placed between the pit and the recuperator. The products of combustion pass through horizontal flues in the tile-constructed recuperator, and the air through vertical flues. The soaking pit is in operation at the plant of the Donner Steel Co., Buffalo.

W. Trinks, *Recuperators for Industrial Furnaces* (Proceedings of the Engineers' Society of Western Pennsylvania, 1927, vol. 42, Jan., pp. 465-490; Fuels and Furnaces, 1927, vol. 5, July, pp. 851-853). The author discusses the economics of the use of recuperators, explains the principles underlying their construction and employment, and describes the following makes of recuperator: The Amsler-Morton, the Calco, the Duraloy, the Fitch, the Mantle, the Morgan, the Smith, the Chapman-Stein, and the Blaw-Knox regenerative air heater.

Unusual Billet-Charging Equipment (Iron Age, 1927, vol. 120, Oct. 20, p. 1085). An overhead crane with a span of 60 ft., with an automatic control board in the power-house, is used at the plant of the Phoenix Iron Co., at Phoenixville, Pa., to charge billets into a heating furnace. The billets are picked up by means of a bipolar lifting magnet, with a control box containing a row of push buttons, and carried by the operator by means of a strap around his neck.

C. Mettegang, *Reconstruction of the Reheating Furnaces of the Phoenix Company at Ruhrort* (Stahl und Eisen, 1927, vol. 47, June 23, pp. 1033-1047). Within the last few years three groups of reheating furnaces

at the Phoenix Works have undergone reconstruction. The furnace for the high-speed mill, rolling light material, was previously a recuperative continuous furnace of the Bender and Frambs type. This has been replaced by a Siemens regenerative furnace with water-cooled skids and other improvements, whereby the output has been increased by 50 to 60 per cent. The furnace was at first fired with mixed gas composed of blast-furnace gas 45, producer-gas 35, and coke-oven gas 20 per cent., admitted at a pressure of 40 mm. water-gauge and a temperature of 350° C., the calorific value being about 1800 kg. cal. The coal consumption was 9.5 per cent. weight of that of the material charged. Coke-oven gas firing has now been adopted, whereby the coal consumption has been lowered to 6.5 per cent. The mill for small sections is served by a Siemens regenerative furnace fired with mixed gas, and the mill for medium sections by a similar furnace fired with blast-furnace gas, with a connection for coke-oven gas if necessary. The coal consumption is about 10 per cent. of the weight of the charge. The rail mill is served by a furnace with a stepped fire grate. Straight coke-oven gas is used, and the coal consumption is about 7.5 per cent. of the weight of the charge. Coke-oven gas is found to be the most economical fuel of any, but a careful watch must be kept to avoid burning the charge. The furnaces described are well illustrated.

G. Bulle, *Heating Furnaces Fired with Powdered Coal* (Stahl und Eisen, 1927, vol. 47, May 19, pp. 817-826; June 2, pp. 915-920). The development of the use of coal-dust firing in iron and steel works is reviewed. The author deals in particular with the system as applied to reheating furnaces, and sectional drawings of coal-dust burners and of various types of reheating furnaces are shown. In view of the economy of the system as compared with gas firing, the use of coal-dust firing for reheating furnaces will undoubtedly spread.

M. H. Mawhinney, *Furnaces for Forging and Heat Treating* (Forging, Stamping, Heat Treating, 1927, vol. 13, Sept., pp. 374-376). Design, construction, burners, fuel saving, insulation, and automatic control of fuel are discussed. The types of furnace considered are non-continuous.

E. F. Davis, *Modern Furnaces and Heat-Treating Methods* (Transactions of the American Society for Steel Treating, 1927, vol. 12, Aug., pp. 291-302). The author discusses the various methods in use for forging, hardening, and tempering of steel. He also discusses the merits of the different methods and types of furnaces used in heating metal parts.

F. G. Bell, *Reheating and Heat-Treatment Furnaces* (Fuel Economy Review, 1927, vol. 6, pp. 46-52). The author gives particulars of experiments carried out to improve the efficiency of coal-fired heating furnaces by utilisation of the heat in the waste gases and of that radiated from the roof structure preheating the combustion air. Several types of furnaces are illustrated, and details are given of operating results.

Charging and Discharging Machine for Industrial Furnaces (Engineering, 1927, vol. 124, July 29, pp. 136-137). The furnaces with which the machine here described is used have several longitudinal grooves formed in the floor. The work to be charged into the furnace is placed on the carrier bars of the charging machine, and these carrier bars travel into the furnace, sets of rollers on the lower sides of the carrier bars rolling on the bottoms of the grooves. When the work is in the furnace the top portions of the carrier bars slide down inclined planes attached to the lower portions, thus depositing the work on the floor of the furnace and releasing the carrier bars for withdrawal. For discharging the furnace the procedure is reversed. One type of machine was specially designed to handle plates 60 ft. long by 9 ft. wide weighing about 15 tons each; lighter machines are built which are capable of travelling sideways to serve several furnaces. The heavier machines are electrically operated, but a small machine dealing with loads up to 3 tons is hand operated.

H. C. Armstrong, *Characteristic Furnace Curves as an Aid to Fuel Control* (Engineer, 1927, vol. 144, Oct. 21, pp. 445-447). The author discusses the heating of bodies in furnaces, and describes how a graph characteristic of any furnace may be drawn up, and the furnace controlled by means of the graph. He adds a word on furnace testing, and on improvements to be looked for in furnace design.

M. H. Mawhinney, *Effect of Height of Stack on Furnace Operation* (Fuels and Furnaces, 1927, vol. 5, May, pp. 579-581). The author has studied the pressure conditions in an oil-fired mill furnace as affected by the height of the stack. As the height of the stack is increased, furnace pressure varies rapidly with variations in fuel consumption, and changes in pressure are much greater.

Economies Result from Change in Fans (Forging, Stamping, Heat Treating, 1927, vol. 13, Aug., pp. 306-307). By altering the air supply system to their forges and furnaces from a central blower to individual furnace units the Cincinnati Car Co. have effected very appreciable economies. The old and the new plant are briefly described, and the savings made on the new installation are summarised.

Forging and Stamping.—E. Blau, *Economy in Using Air for Power* (Iron Age, 1927, vol. 120, July 21, pp. 131-134). According to the author, the cost of forging, pressing, and shearing is greatly reduced by the substitution of air for steam. No change in the design of forging hammers is necessary. Air is heated to about 480° F., utilising the waste gases from the furnaces. Maintenance costs are lower when air is used for power, and the delay in starting due to condensation is avoided. Several methods of application of compressed air are given.

15-Ton Steam-Lift Free-Tup Drop-Forging Hammer (Engineering, 1927, vol. 123, June 24, pp. 765, 768). The cardinal feature in the hammer, on the Schneider-Urbanc system, described in this article, is an elastic connection between the piston of a steam-hammer and

the tup, so that the latter rebounds slightly, thus combining all the advantages of a free-falling tup with those of a steam lift. Further, the framing itself is provided with elastic couplings in the form of spring-loaded bolts.

C. Longenecker, *Billings and Spencer Forge Plant* (Forging, Stamping, Heat Treating, 1927, vol. 13, Aug., pp. 312-315). A description of the works of the Billings and Spencer Co., one of the pioneers of the drop-forge industry in America.

G. Sachs, *Experiments on the Rolling and Forging Processes* (Zeitschrift für Metallkunde, 1927, vol. 19, May, pp. 189-195). The author deals with both ferrous and non-ferrous materials. He shows that, if the process of the shaping of materials is to be understood, the experiments must be made to conform as closely as possible to the conditions existing in practice. The appearance of tears when rolling sheets and profiles is to be attributed to uneven displacements of the metal during the process.

D. C. Price, *Lubrication of Steam-Hammers* (Forging, Stamping, Heat Treating, 1927, vol. 13, Sept., pp. 360-361). The difficulties encountered in lubricating steam-hammers, and means for overcoming them, are described. The oil should be filtered, and heated when the temperature is low.

The Flow of Metals in Forging (Forging, Stamping, Heat Treating, 1927, vol. 13, July, pp. 248-252, 275). The internal structure of metals in the cast and in the forged conditions is discussed, and the importance of the "flow lines" in forgings in conferring strength and durability when they are correctly situated is pointed out. Etching methods to reveal flow are described.

H. R. Simonds, *Submarines Require Finest of Steel* (Iron Trade Review, 1927, vol. 81, Aug. 11, pp. 311-314). The general procedure for the forging and heat treatment of Diesel engine crankshafts for submarines is outlined.

Heavy Duty Chain made by New Method (Iron Trade Review, 1927, vol. 81, Oct. 13, pp. 897-898, 908). Illustrated particulars are given of the manufacture of chain at an American plant. The chain is made up of forged heat-treated half-link sections, which are joined in dies under the steam-hammer.

F. W. Manker, *Studebaker Axles and Crankshafts* (Iron Age, 1927, vol. 120, Aug., pp. 332-334). A brief account is given of the drop-forging and heat treatment of automobile axles and crankshafts. Heat treatment on rough forgings consists of normalising, followed immediately by hardening and quenching in oil.

J. Pitscheneder, *Principles of Swage Forging* (Werkstattstechnik, 1927, vol. 21, Aug., pp. 437-440). The author presents a brief historical sketch and discusses methods for efficient swage forging.

K. Roeser, *The Forged Ploughshare* (Kruppsche Monatshefte, 1927, vol. 8, May, p. 99). A note is published on the drop-forging of ploughshares. The kind of steel used has, in the completely annealed

condition, a tensile strength of 85 kg. per sq. mm., an elongation of 12 per cent. on a length = 10 diams., and very high resistance to wear. By treatment the strength and wear resistance can be varied to suit particular conditions of soil.

C. J. Stiers, *Sand-Blasting Forged and Treated Parts* (Forging, Stamping, Heat Treating, 1927, vol. 13, Sept., pp. 367-368). The advantages of this manner of cleaning are enumerated.

R. L. Rolf, *The Art of Forging* (Forging, Stamping, Heat Treating, 1927, vol. 13, Jan., pp. 12-17, 23). The author relates the early history of the production of iron, and describes the evolution of the art of forging.

E. V. Crane, *What Happens in Shearing Metal* (Machinery, 1927, vol. 30, May 26, pp. 225-230). An analysis of the action of the tools and the behaviour of the metal in shearing, blanking, or punching; the factors affecting the pressures required are discussed, and results obtained are recorded.

O. Engelbach, *Repair Workshops in Iron and Steel Works* (Stahl und Eisen, 1927, vol. 47, Aug. 18, pp. 1357-1363). Repair workshops are essential branches of the organisation in an iron and steel works with its continuous output. They should be arranged so that stoppages can be relieved in the shortest possible time. Engineers and foremen should be entrusted with the supervision of all productive machinery. The workshops are also responsible for the readiness of replacements and spares. A party of experienced fitters equipped with the necessary means should be trained to deal rapidly with emergencies. The stock of spares should be reduced by striving for the greatest possible uniformity of machinery parts.

Rolling-Mill Practice and Equipment.—*New Three-High Blooming Mill at the Works of Società Italiana Ernesto Breda, Milan* (Iron and Coal Trades Review, 1927, vol. 114, June 24, pp. 994-995; Blast-Furnace and Steel Plant, 1927, vol. 15, Sept., pp. 441-443). An illustrated description is given of this mill, which is designed to roll blooms weighing up to 2 tons. Particulars are also included of the electric driving and auxiliary equipment.

T. Harvey, *The Steel Mill at the Ford Plant* (Blast-Furnace and Steel Plant, 1927, vol. 15, May, pp. 212-216). A brief description of the plant as a whole is given, followed by a complete description of the merchant and blooming mills, their motors and the controls. Projected developments and equipment are mentioned.

C. A. Menk, *New Homestead Structural Mills* (Paper read before the Association of Iron and Steel Electrical Engineers: Iron Age, 1927, vol. 119, June 23, pp. 1815-1816). R. H. Wright, *Carnegie Structural Mill at Homestead* (Blast-Furnace and Steel Plant, 1927, vol. 15, July, pp. 331-334). The new structural mills of the Homestead Works of the Carnegie Steel Co. consist of two groups—No. 1 group being made up of a 44-in. blooming mill, a 36-in. roughing mill, and a 28-32-in.

finishing mill. These mills are designed to roll the standard structural shapes, channels, I beams, angles, &c. The finished product varies in size from 6×4 -in. angles to 24-in. I beams. No. 2 group consists of a 54-in. blooming mill and a 52-in. Carnegie beam mill. Particulars are given of the electric drive recently installed in these mills.

E. C. Kreutzberg, *Celebrates its 137th Year by Installing New Four-High Plate Mill* (Iron Trade Review, 1927, vol. 80, June 9, pp. 1475-1476). *Tandem Mill for Wide, Thin Plates* (Iron Age, 1927, vol. 119, May 19, pp. 1431-1434). The new 84-in. plate mill of the Lukens Steel Co. at Coatesville, Pa., is described and illustrated. It is of the tandem motor-driven type, and consists of a two-high roughing stand and a four-high finishing stand. The equipment also includes tables with transfers, blue annealing furnace, roller leveller, cooling conveyors, inspection bed, and new types of rotary side trimming shears and end shearing equipment, to do away largely with the necessity for marking out of plates before shearing, as is common practice in plate mills. In the four-high stand the rolling is done between the two middle rolls of chilled iron, these rolls being supported by top and bottom 40 in. diameter backing-up rolls, the necks of which carry the rolling load. The annealing furnace is 40 ft. long and 8 ft. wide, and is designed to heat approximately 12 tons of $\frac{1}{4}$ -in. plates 60 in. wide, as delivered from the mill. A special non-cooled alloy is used for the conveyor rolls in the furnace.

W. Krämer, *The Sheet Rolling-Mill* (Stahl und Eisen, 1927, vol. 47, Feb. 10, pp. 209-219; Mar. 3, pp. 352-358; Mar. 10, pp. 399-406; translation, Iron and Coal Trades Review, 1927, vol. 115, July 22, pp. 126-127; July 29, pp. 164-165; Aug. 5, pp. 200-201; Aug. 12, pp. 230-231).

Changing Mills with Minimum Delay (Iron Age, 1927, vol. 120, Aug. 18, pp. 394-396). Illustrated particulars are given of the new 19-in. continuous sheet bar mill at the plant of the Inland Steel Co. Previous to the erection of the new mill billets and sheet bars were rolled on a 24-in. three-high mill served by a 36-in. blooming mill. In the rearrangement one stand of the 24-in. mill, with its lifting tables and manipulators, is retained for use as an independent billet mill. The new mill consists of two stands of 24-in. rolls, six stands of 19-in. rolls, and four sets of vertical edging rolls located respectively before the first, third, fifth, and seventh horizontal stands.

S. Badlam, *The Evolution of the Wide Strip Mill* (Paper read before the American Iron and Steel Institute, Oct. 1927). The rolling of wide thin sections has developed along two distinct and originally widely separated lines: (1) the rolling of strip, characterised by limitations in width and gauge, rather than in length; (2) the rolling of sheets characterised by limitations in length, rather than in width and gauge. The first mill definitely designed for the production of 16-in. wide strip was built by the American Tube and Stamping Co., Bridgeport, Conn., in 1905. This was a semi-continuous mill. The author traces

chronologically the successive mills marking development or departures from previous practice, each mill being briefly described. The development of the four-high mill is also traced. The character and extent of the advance in rolling-mill practice, represented by the new broad strip mills and by the continuous sheet mills, is shown in the following statement of the maximum widths rolled in the various gauges :

A—Hand-operated strip mill, 1900–1905.

B—Tandem rougher, strand finisher, strip mill, 1905–20.

C—Tandem rougher, continuous finisher, strip mill, 1920–25.

D—Four-high tandem finisher, broad strip mill, 1926–27.

E—Continuous sheet mill, 1924.

Thickness.		Maximum Width. Inches.				
Inches.	B.W.G. No.	<i>A.</i>	<i>B.</i>	<i>C.</i>	<i>D.</i>	<i>E.</i>
0·049	18	8	6	9 $\frac{1}{4}$	...	...
0·065	16	10	10	15	25	42
0·083	14	12	13 $\frac{1}{2}$	18	...	...
0·109	12	...	16	21	...	...
0·134	10	...	17	23	...	...

Trumbull Company's Wide Strip Mill (Iron Age, 1927, vol. 120, Sept. 15, pp. 693–696); *New Wide Stripsheet Mill Employs Electric Driven Screwdowns* (Iron Trade Review, 1927, vol. 81, Sept. 15, pp. 656–659). The layout and equipment of the new hot strip mill of the Trumbull Steel Co. for the continuous rolling of sheets and wide strip steel is described and illustrated. The mill, which can produce strip steel up to 30 in. wide, consists of three slab heating furnaces, five two-high roughing stands, three vertical edging mills, five four-high finishing stands, with necessary roller tables, cooling bed, shears, reel, and other auxiliary equipment. The whole of the plant has been arranged to permit of the straight flow of materials from the furnaces to the cooling beds, and in its straight line course the material moves about 650 ft.

F. B. Pletcher, *Roll Thin Strip Steel on Four-High Mill* (Iron Trade Review, 1927, vol. 80, May 26, pp. 1329–1331); *Laclede Hot-Rolled Strip Mill* (Iron Age, 1927, vol. 119, May 26, pp. 1525–1527). Illustrated particulars are given of the electrical equipment of the new hot strip mill of the Laclede Steel Co., St. Louis. The mill is capable of rolling strip from 0·035 in. to $\frac{3}{8}$ in. in thickness and up to 12 in. in width. The billets are broken down in four stands of Morgan horizontal roughing rolls, and finished in five four-high stands of finishing rolls. Complete electrification of the mill has been provided for.

A. E. Beardmore, *New Sheet Bar and Skelp Mill at Indiana Harbour* (Iron and Steel Engineer, 1927, vol. 4, July, pp. 342–345). The electrical driving equipment of the sheet bar and skelp mill at the Indiana Harbour plant of the Youngstown Sheet and Tube Co. is described and illustrated.

D. N. Watkins, *Wheeling Steel Corporation's New Skelp Mill* (Blast-Furnace and Steel Plant, 1927, vol. 15, Sept., pp. 435-437). A brief illustrated description of the Wheeling Steel Corporation's new skelp mill at their Benwood Works. The mill is capable of rolling long strips of skelp at the rate of 600 to 1200 ft. a minute; it consists of 10 stands of horizontal mills and 4 sets of vertical edging rolls, the stands being placed in pairs and each pair being separated by one set of edging rolls. The mill is electrically driven.

J. D. Knox, *Rolling Stripsheet on New Continuous Mill* (Iron Trade Review, 1927, vol. 80, May 19, pp. 1271-1275); *How Stripsheets are Rolled on Continuous Mill* (Iron Trade Review, 1927, vol. 80, May 26, pp. 1344-1346); *Continuous Annealing Promotes Uniform Structure in Stripsheets* (Iron Trade Review, 1927, vol. 80, June 2, pp. 1398-1400, 1433); *Continuous Rolling of Sheets at Butler, Pa.* (Iron Age, 1927, vol. 119, May 19, pp. 1435-1439). The methods and equipment employed by the Columbia Steel Co. for the production of strip up to 36 in. in width are described and illustrated. Slabs are heated in a continuous furnace and are discharged direct on to the roller tables of a universal roughing mill. The slabs after breaking down and without further heating are passed through a continuous four-high finishing train. They are then coiled ready for annealing and pickling. The steel in a continuous sheet comes from the pickling and washing vats, and is sheared to length or may be re-coiled for the cold-rolling department. Abutting ends of the sheets are spot welded to maintain the continuous movement through the vats, and the shear at the issuing end serves also to cut out the short welded sections. The sheets have been given the name of "stripsheets."

J. D. Knox, *Rolls Sheet Steel Direct from Ingot Without Reheating* (Iron Trade Review, 1927, vol. 80, June 16, pp. 1532-1535); *Continuous Sheet Mill is Based on Proportional Convexity* (Iron Trade Review, 1927, vol. 80, June 23, pp. 1593-1596); *Sheets Rolled to 16-Gauge on Three-High Backup Mill* (Iron Trade Review, 1927, vol. 80, June 30, pp. 1656-1659); *Sheets Reduced to 20 Gauge on Continuous Mill by Loose Rolling Method* (Iron Trade Review, 1927, vol. 81, July 7, pp. 8-12); *Anneal and Pickle Sheets by Continuous Method* (Iron Trade Review, 1927, vol. 81, July 14, pp. 67-70); *Exceeds Ton of Sheets per Minute* (Iron Age, 1927, vol. 119, June 16, pp. 1731-1737, 1792). Detailed descriptions are given of the continuous sheet mill of the American Rolling Mill Co., at Ashland, Kentucky. Ingots 19 × 39 in. in section are bloomed down to slabs 4 in. thick, 36 in. wide, and 23 ft. long. After passing through a holding furnace, the slabs are sheared and then reduced in a continuous bar plate mill. This mill consists of seven two-high stands operated in tandem, the slabs being reduced to $\frac{7}{16}$ in. bar plates. From this mill the bar plates go to a jobbing or rough plate mill. Before entering the continuous sheet mill, the rough plates are matched in pairs, and sheared. These then enter a continuous heating furnace 140 ft. in length. From this point packs of matched

pairs are passed through five three-high stands. After the second, third, and fourth stands are placed reheating furnaces to maintain proper rolling temperature. The sheets are then sheared, and given a continuous strip annealing and pickling operation. Side trimmers and two cut-off shears in tandem prepare the sheets for a stitching machine, which staples the sheets into a continuous ribbon. This is passed in succession through the annealing furnace, cooling hood, pickler, and then to shears for cutting out the overlapped staples. Provision for taking up slack in the space between the stitching machine and the annealing furnace has been made by a series of loops.

C. Longenecker, *Continuous Sheet Mill at Ashland* (Blast-Furnace and Steel Plant, 1927, vol. 15, July, pp. 335-338, 346).

New Alloy Bar Mill at Chicago (Iron Age, 1927, vol. 120, Sept. 15, pp. 729-731); *Bar Mill Designed Essentially for Alloy Steel Sections* (Iron Trade Review, 1927, vol. 81, Sept. 15, pp. 662-665). A detailed description is given of the layout and equipment of the alloy steel bar mill at the South Works of the Illinois Steel Co., Chicago. In the heating furnaces the atmosphere is kept as non-oxidising as possible, and the blooms or billets are protected from direct contact with the gases and flames; in order to ensure a minimum quantity of scale and surface decarbonisation. The mill consists of thirteen stands, each driven by a separate variable-speed direct-current motor.

W. C. Sutherland, *The Pilger Tube Mill of the Pittsburg Products Steel Co.* (Paper read before the American Iron and Steel Institute, May 1927). A detailed illustrated description is given of this mill, which is designed to roll tubes of extremely long lengths direct from the ingot. Two continuous furnaces 70 ft. long by 10 ft. wide, and fired with natural gas, are employed for heating the blanks preparatory to piercing. The piercing mill is of the Mannesmann type, and is of extremely heavy and rugged design. The working rolls are 23 in. in diam., and the top and bottom guides are rollers of 12 in. diam. All adjustments of this mill are made by the use of motors driving through gear or worm reductions. The ingot after piercing is sent to the Pilger mills without further heating. There are two Pilger mills at this plant, set in line and driven by a 2000-H.P. d.c. motor. After leaving the hot saw the tubes are reheated and carried to the sizing mill. The sizing operation also serves to break up the scale formed on the inside of the tubes as the result of the reheating operation; this scale is later blown out of the tube by compressed air. On leaving the sizing mill the tube passes through a pair of crossed rolls or a hot straightener and is discharged on to the cooling rack. This tube mill is capable of producing tubes from 6 to 12 in. in diam. by 46 ft. long or over. The nominal capacity of the mill is about 300 tons per day.

G. Löbkowitz, *Principles for the Design of Pilger Mills* (Stahl und Eisen, 1927, vol. 47, Aug. 4, pp. 1277-1283). The article is mainly a mathematical treatment of the subject. Pressure measurements, to determine the dimensions of the rolls, were undertaken in a Pilger mill

whilst rolling 5-in. and 12-in. tube. Calculations of the dimensions of the roll cone, the size of pass, and the theoretical output are given, based on the revolutions at which a particle of the rolled material makes contact with the working pass. The form of the roll cone was found to be a hyperbola with the co-ordinate axes as asymptotes, on the assumption that the section rolled and velocity of passage through the rolls are constant for each pass. De Grahl's opinion, based on constant speed conditions, is that the roll cone is of parabolic form. The work and action of the feeding apparatus are described.

J. Gassen, *The Mechanism of Skew Rolling* (Archiv für das Eisenhüttenwesen, 1927, vol. 1, Aug., pp. 127-136). A theory of piercing, based on practical and theoretical considerations, was evolved. This theory offers a foundation for further detailed work. Directions are given for the design of the skew or transverse rolls, shape of the mandrel, and the determination of the angles of pass and inclination, with indications of the interdependence of these factors. The experimental results lead to practical proposals for the rolling of tubes up to very large diameters. The extension in transverse rolling is limited to about $3\frac{1}{2}$ to 4, so that a finished tube requires a round billet whose diameter is much smaller than that of the tube. If a Pilger mill is to be dispensed with, a rolling process in which the billet is not rotated must be used. Such a mill with four rolls is described in the paper.

E. Siebel, *Fundamental Considerations on the Piercing by Skew Rolling Process* (Stahl und Eisen, 1927, vol. 47, Oct. 13, pp. 1685-1691). A review shows that we are far removed from a complete and comprehensive knowledge of the piercing process. But we possess a qualitative picture of the forces, stresses, and deformation between the rolls, without being able to give exact expressions to the various influences under which piercing occurs. The position is more favourable as regards the power requirement for piercing; the minimum work may be calculated, and used as a gauge in manufacture. For further progress a complete investigation of the separate Friemel process and transverse rolling on the mandrel is necessary, with measurement of the forces and work. Investigations into the stresses in the material, the resistance of the material to deformation, and on the contact conditions between rolls and material are necessary. The foundations required for complete comprehension of this complex process will then first become available.

F. Kochs, *Skew Rolling* (Stahl und Eisen, 1927, vol. 47, Mar. 17, pp. 433-446): abstract, *The Mannesmann Tube Mill* (Metallurgist, 1927, May 27, pp. 68-69). See Journ. I. and S.I., 1927, No. I. p. 888.

G. A. Richardson, *Sparrows Point Wire and Rod Mill* (Iron Age, 1927, vol. 119, May 5, pp. 1291-1297). An illustrated account is given of the new rod and wire mill of the Maryland plant of the Bethlehem Steel Co. at Sparrows Point. The 10-in. rod mill is of the Morgan electrically operated two-high continuous type, and is entirely gear

driven. It consists of seven roughing, nine intermediate, and one finishing stand. The wire-drawing equipment is of the latest type, most of the blocks being single-head, and a few of the double-head type. Each block is driven individually by a 20-H.P. d.c. motor, with control gear for any speed between the limits of 50 to 15 r.p.m. A device is used which automatically stops the wire-drawing blocks when a kink or snarl occurs in the rod or wire.

E. Richarme, *Study of Wire Mills* (Revue de Métallurgie, Mémoires, 1927, vol. 24, Apr., pp. 161-178; May, pp. 255-277; June, pp. 307-316; July, pp. 405-414). The author deals very thoroughly with the subject of wire mills and their auxiliary plant from both the practical and the theoretical aspect. He discusses the diameter of the wire rolled, the quality of the metal, the weights of the blooms and billets, the tangential speed of the finishing rolls, multiple wire rolling, the theoretical output of wire mills, the design of the rolls used, the relation between the section of the bar and the tangential speed of the rolls, the temperature difference between the ends of the same bar, "running-out" of wire, determination of the angular velocities of wire mills, the power of the electric driving motors, electric motors and flywheels, the work done in rolling, roll bearings, winders, the wire mill staff, output, &c. Various types of wire mills, in different parts of the world, are described.

E. W. Duston, *Cold-Rolling Mill of Recent Design* (Blast-Furnace and Steel Plant, 1927, vol. 15, Nov., p. 551). A brief description of a special design of an electrically driven mill of six units for the manufacture of bolt and nut stock. The first unit is a 10-in. flat mill, the third and fifth are 8-in. mills, the second and fourth are edging mills, and the last is a take-up reel or block.

Electric Drive for the Reversing Mill at Margam (Iron and Coal Trades Review, 1927, vol. 115, Oct. 14, pp. 563-564). An illustrated account is given of the electric equipment for driving the reversing mill at the Margam, South Wales, works of Messrs. Baldwin, Ltd.

Blooming Mill Given Electric Drive (Iron Age, 1927, vol. 120, July 28, pp. 203-204). Particulars are given of an electric drive for a two-high reversing 34-in. blooming mill recently placed in operation at the Upson plant of the Bourne-Fuller Co., Cleveland, U.S.A.

C. A. Menk, *Electrical Installations of New Structural Mills, Homestead Steelworks, Carnegie Steel Co., Munhall, Pa.* (Iron and Steel Engineer, 1927, vol. 4, June, pp. 308-321). The electrical driving equipment of the new structural mills at this plant is illustrated and described in detail.

S. Ghosh, *The Electrification of Tata Iron Works at Jamshedpur* (Iron and Steel Engineer, 1927, vol. 4, Sept., pp. 404-413). A detailed description is given of the electric driving equipment for the rolling-mills at this plant.

J. F. Jelley, *Electrifies Finishing Mill Drives* (Iron Trade Review, 1927, vol. 81, Aug. 11, pp. 319-321). An account is given of the new

electric equipment for the rolling-mill plant of the Phoenix Iron Co., Phoenixville, Pa.

W. H. Burr, *Electrical Developments in the Iron and Steel Industry* (Iron and Steel Engineer, 1927, vol. 4, June, pp. 297-302). Recent developments in the use of electricity for rolling-mill drives, cranes, and other equipment are summarised.

S. Ekelund, *Dynamic Conditions in Connection with Rolling* (Jernkontorets Annaler, 1927, vol. 111, pp. 39-106). Power requirements and other conditions in rolling are discussed, and the author presents theoretical calculations.

L. Persoz, *The Electrification of Steam-Driven Blooming Mills* (Génie Civil, 1927, vol. 90, Mar. 26, pp. 316-317). The author discusses the conditions under which the replacement of steam drive by electric drive for blooming mills is economically sound.

L. A. Umansky, *Speed Regulation of Main Roll Drives* (Iron and Steel Engineer, 1927, vol. 4, May, pp. 207-218). The author discusses the formation and control of loop, characteristics of electric drives, and external means of improving the regulation. It is pointed out that the speed regulation is only indirectly related to the problem of maintaining the loop and, therefore, to the question of operating the mill.

Motor-Driven Table Rollers (Iron Age, 1927, vol. 119, June 9, pp. 1663-1664); *New Roller-Table Rolls Inclose Their Individual Driving Motors* (Iron Trade Review, 1927, vol. 80, June 9, pp. 1470-1471). The table rollers described are driven by a motor contained within the roller shell. A stationary shaft carries the stator core and coils of a 3-phase a.c. motor, while the outer shell containing the rotor core and squirrel cage revolves, thus providing a power unit that serves as a roller. Designed for a peripheral speed of 130 ft. to 3000 ft. per minute, the speed of the rollers is determined by the number of poles used in the motor winding and the frequency of the supply current. Speed adjustment, if desired, may be obtained by varying the power circuit frequency.

H. Cramer, *The Draughting of Rolls for Three-High Mills, with Reference to High Economy in Wear of Rolls* (Stahl und Eisen, 1927, vol. 47, May 5, pp. 739-742; translation, Iron and Coal Trades Review, 1927, vol. 115, July 15, pp. 96-98). A discussion of the best method to pursue in re-turning and dressing the worn passes of rolls so as to secure the longest possible life for the rolls before consignment to the scrap-heap. It should be possible to re-turn a roll six times, while preserving the original dimensions of the pass, before scrapping. If a slight widening of the passes, by not more than 3 mm., is permissible, twelve re-turnings become possible.

L. Frielinghaus, *A New Type of Main Coupling for Rolling Mills* (Stahl und Eisen, 1927, vol. 47, July 14, pp. 1177-1178). The Ortmann coupling is now almost exclusively used in rolling-mills between the engine, motor, or flywheel and the driving pinion. Radial play is practically eliminated in recently improved arrangements. In the new

Schloemann coupling circumferential play is also eliminated by fitting bronze pads, square externally, over the round dogs of the coupling ends. These pads press directly against the collar insets. The coupling can be built for the greatest moments likely to be produced, and is especially suitable for tube mills.

W. R. Kneeland, *Rough Sheet and Tin-Mill Rolls* (Iron Age, 1927, vol. 120, July 7, p. 13). The author discusses the cause of roughness in hot-rolling, which he terms "crazing," and suggests a remedy to eliminate this trouble.

H. Cramer, *Theory and Practice in "Ragging" Rolls* (Blast-Furnace and Steel Plant, 1927, vol. 15, July, pp. 326-328; abstract, Journ. I. and S.I., 1927, No. I. p. 889).

P. H. Frank, *Measuring Pressures on Bearings of Rolling Machinery* (Iron Trade Review, 1927, vol. 8, Oct. 20, pp. 965-966). Particulars are given of two methods for the determinations of load pressures to which anti-friction bearings are subjected in heavy duty rolling machinery.

Roller Bearings for Rolling-Mills (Engineering, 1927, vol. 123, Apr. 15, pp. 465-467). A review of the difficulties facing the designer of roller bearings for rolling-mills, and an account of the manner in which the Skefko Ball Bearing Co., Ltd., has overcome them. Various types of roller bearings are illustrated and described.

C. J. Klein, *Bearings for Use in Rolling-Mills* (Iron and Steel Engineer, 1927, vol. 4, June, pp. 271-274). The author describes and illustrates some of the typical bearing arrangements used in connection with rolling-mills and auxiliary equipment.

F. H. Buhlman, *Factors Governing the Design of Roller Bearings for Roll Necks* (Iron and Steel Engineer, 1927, vol. 4, June, pp. 302-307).

E. C. Gainsborg, *Anti-Friction Bearings on Roll Necks of Rolling-Mills* (Iron and Steel Engineer, 1927, vol. 4, June, pp. 274-276).

F. Waldorf, *Application of Tapered Roller Bearings on Roll Necks of Rolling-Mills and Pinion Stands* (Iron and Steel Engineer, 1927, vol. 4, June, pp. 265-271). The author presents the results of a series of tests carried out to determine the exact requirements of the bearing equipment and installation for rolling-mills. Results show the possibility of very considerable savings in power by the use of roller bearings on the roll necks. The Brinell test was used to determine the load to which the bearings were subjected.

W. A. Reynolds, *Lubricating Continuous 10-in. Merchant Bar-Mill* (Iron Trade Review, 1927, vol. 81, July 14, pp. 83-84). A lubricating system for a merchant bar-mill is briefly described. The mill has a complete pressure oiling system ensuring a circulation of 800 gallons of oil per hour. Provision is made for temperature control and complete purification of the lubricant.

G. Fox, *Electric Roll Heater Facts* (Freyn Design, 1926, vol. 1, Apr., pp. 10-11). The electrical heating of sheet and tinplate rolls is briefly discussed, and a comparison is made with other methods of heating.

E. Dechert, *Hypo-Eutectic Castings for Rolling-Mill Guides* (Fonderie Moderne, 1927, vol. 21, Apr. 10, pp. 49-51). The author presents the results of tests on two types of castings carried out to determine the best composition of metal for wire and rod mill guides.

British Rolling-Mill Practice Reviewed (Blast-Furnace and Steel Plant, 1927, vol. 15, Nov., pp. 524-525). The couplings, pinion housings, slip-drive, spindles and bed-plates, and a new type of patent universal spindle, as used in Great Britain, are described, and their points of superiority over similar foreign-made parts are enumerated.

W. Tafel and G. Pajunk, *Determination of Spread in the Horizontal Layers of Rolled Material* (Stahl und Eisen, 1927, vol. 47, Sept. 22, pp. 1562-1565). The various theories of spreading are discussed, also the method employed to determine the spread on wide bars (up to 12 in.) and at heavy draughts (up to 50 per cent.). The tests showed that the spread is different in the various horizontal planes of a rolled material. The spread at the two edges is often different from that at the interior. In general, it varies uniformly from the centre of the bar to the edges.

N. Metz, *Experimental Investigation on the Flow of Material in Rolling* (Archiv für das Eisenhüttenwesen, 1927, vol. 1, Sept., pp. 193-204). It is possible to follow the flow of the steel when rolling flats by fitting screws into various points of the material; and by this means to observe conditions of free spreading, and the effect of different pressure and of temperature differences in the section. Tension stresses in the side surfaces of flats were considered to be due to a reduction of pressure caused by a displacement of parts of the side surfaces to the top and bottom. The spread was investigated by examining the height ratio h_1/h_2 at various pressures, original widths and thicknesses. A new method of calculating the spread was proposed. Spread increases with increased roll diameter and rolling speed. The flow of material within the angle of attack was investigated by observing the alteration of notches in the sides. Movement of material already occurs outside the angle. Longitudinal upsetting, that is, an increase in section, may be caused by a sudden reduction in the speed of the bar on leaving the rolls. The displacement of material in various passes was also tested. The method of calculating spread for flats is also employed for these sections. Further, the movement in rail upsetting passes is followed, and the results enable the flange width after the pass to be calculated. The tensions in the flanges in the pass, after the upsetting pass, are explained.

H. F. Lichte, *High Capacity Machine Tools for Mill Rolls, with Special Reference to Roll Grinding* (Stahl und Eisen, 1927, vol. 47, July 21, pp. 1209-1212). The development in such machine tools is due to the demand for greater accuracy, in addition to the requirement of decreased working costs. Modern types of roll turning lathes, pinion milling machines, roughing machines, and grinding machines are described. It is considered that the demands of mills, as to the accuracy of these

rolls, are completely met by modern roll machine tools and measuring instruments.

The Demag Roller Straightening Machines (Engineering, 1927, vol. 124, Sept. 2, pp. 295-296, 300). Brief descriptions of the various types of roller straightening machines made by the Deutsche Maschinenfabrik "Demag" are given.

H. Jordan, *Management, Statistics, and Costs in Rolling-Mills* (Archiv für das Eisenhüttenwesen, 1927, vol. 1, July, pp. 41-46). A knowledge of rolling costs is indispensable for mill management. Statistics, based on control measurements, provide the more valuable foundation. Material, energy, and time data and the means of obtaining them are considered. Index figures for criticising costs are obtained from such data. By following certain directions the cost in mills may be compared, which is a matter of private and general economical significance.

A. Körver, *Controlling Operation Through Time Keeping* (Centralblatt der Hütten- und Walzwerke, 1927, vol. 31, Aug. 31, pp. 487-492). The author quotes examples and discusses proposals for the use of time recorders in the operation of rolling-mills.

G. P. Raidabaugh, *History of the Rolling of Rails* (Blast-Furnace and Steel Plant, 1927, vol. 15, Apr., pp. 183-185, 197). A brief review of the development of rail sections in America from 1857 to 1910, during which period the weight of rails increased from 50 to 135 lb. (See also Journ. I. and S.I., 1917, No. I. p. 233, with bibliography.)

N. Danielsen, *The Manufacture of Swedish Wire Rods* (Wire, 1927, vol. 2, July, pp. 223-224, 246-247). A brief account of the manufacture and uses of Swedish wire rods. The steel is prepared from Swedish charcoal pig iron, and the great purity of this material, especially as regards sulphur and phosphorus, makes the use of the acid O.-H. process possible.

J. D. Brunton, *The Preparation of Wire Rod for Drawing* (Wire, 1927, vol. 2, Sept., pp. 303-305, 319-321). A description of British practice in pointing, pickling, and handling of wire rod.

J. M. Layng, *Performance of New Installation in Stewart Hartshorn Plant* (Wire, 1927, vol. 2, Aug., pp. 263-264, 281-282). The plant and procedure are described, and an analysis of operating costs is given. 15-gauge high-carbon steel wire is drawn on three two-unit batteries of Morgan-Connor Type A wire-drawing machines.

FURTHER TREATMENT OF IRON AND STEEL.

Cementation and Case-Hardening.—H. B. Northrup, *Case Carburisation of Production Steels by Means of Salt Baths of Low Cyanide Concentration* (Transactions of the American Society for Steel Treating, 1927, vol. 12, Sept., pp. 470-478). The author describes a series of carburising tests carried out on three types of steel by means of a molten sodium cyanide bath maintained at a temperature of 1650° F. The penetration of carbon is shown by means of photomicrographs and charts. In the treatment of steel in cyanide mixtures at a temperature of 1650° F. brittleness is largely eliminated.

A. Bramley and G. Lawton, *The Gaseous Cementation of Iron and Steel. Part III.—The Influence of Hydrocarbons on the Carburisation of Iron and Steel* (Iron and Steel Institute: Carnegie Scholarship Memoirs, 1927, vol. 16, pp. 35-100). Parts I. and II. of this series appeared in the *Carnegie Scholarship Memoirs* for 1926 (vol. 15, pp. 17-174). In the present work it was found that the cementation produced when a carburetted gas was passed over the specimen in one direction only was much more uneven than when carbon monoxide alone was used. Any obstruction to the free circulation of the carburising gas mixture also caused uneven cementation. The effect of varying the rate of flow of the carburising gas was studied and the conditions necessary for uniform cementation over the whole surface of the specimen were determined. Several hydrocarbon vapours, such as xylene, toluene, benzene, petrol, &c., were used, and the effect of varying each of the factors—period of cementation, temperature of cementation, and rate of flow of the carburising mixture—was ascertained; it was found that: (a) the depth of penetration of the carbon increased according to a linear law as the temperature of cementation was raised, within the limits of the experiments; (b) as the period of cementation was increased in geometrical progression the depth of penetration increased in the same way, but with a different common ratio; (c) the depth of penetration was not affected by the rate at which the carburising gas mixture was passed through the furnace, but it appeared to be slightly greater the stronger the cementing agent used.

J. Laissus, *New Researches on the Cementation of Ferrous Alloys by Chromium and Tungsten* (Revue de Métallurgie, Mémoires, 1927, vol. 24, June, pp. 345-352). The experiments described in this paper are intended to give results more accurate than those described in two former papers (*see* Journ. I. and S.I., 1926, No. I. pp. 599, 600; 1926,

No. II. p. 598). The following are the properties studied and reported on here: The surface hardness of the cemented metal, as cemented and after quenching; the resistance to oxidising influences at high temperatures; the ease of polishing; the resistance to corrosion by water; and the resistance to corrosion by various acid solutions.

J. Laissus, *Contribution to the Study of Metallic Cementations. Cementation of Ferrous Alloys by Molybdenum and Tantalum* (Revue de Métallurgie, Mémoires, 1927, vol. 24, July, pp. 377-395). *Contribution to the Study of Metallic Cementations. Cementation of Ferrous Alloys by Vanadium and Cobalt* (Revue de Métallurgie, Mémoires, 1927, vol. 24, Aug., pp. 475-484). In the present papers the structural, mechanical, thermal, &c., properties of cases produced by cementing steel with molybdenum, tantalum, vanadium, and cobalt are described.

M. A. Sanfourche, *Case-Hardening of Steel by Means of Chloride of Silicon* (Métallurgie et la Construction Mécanique, 1927, Aug. 11, p. 19). The author has carried out two series of experiments in which steel was hardened to a depth of 0.3 to 2.7 cm. after $\frac{1}{2}$ to 3 hrs. treatment with chloride of silicon at temperatures ranging from 900° C. to 1150° C.

W. P. Sykes, *Carburising Iron by Mixtures of Hydrogen and Methane* (Transactions of the American Society for Steel Treating, 1927, vol. 12, Nov., pp. 737-758). Concentrations of methane and hydrogen are found to follow closely the theoretical values in atmospheres neutral to steel of given carbon content at temperatures between 1400° and 2012° F. (760° and 1100° C.). It is apparent, however, that for heating conditions which do not approximate to those described in the paper the gas concentrations for neutral atmospheres must be determined by trial. The presence of moisture disturbs the equilibrium of the $\text{CH}_4\text{-H}_2\text{-C}$ system very markedly. A moist gas mixture has less carburising effect than a dry atmosphere of the same methane content (concentrations measured at room temperatures). In carburising iron by the hydrogen-methane atmosphere the depth of carbon penetration is largely determined by the diffusion rate of the carbon. Increase in concentration of methane results primarily in higher carbon content of iron near the surface. By proper concentrations of methane and hydrogen it is possible to carburise uniformly an iron block of $\frac{1}{4}$ in. in thickness to a predetermined carbon content.

L. Guillet, *Nitrogenation of Steels* (Comptes Rendus, 1927, vol. 184, pp. 1296-1299; Génie Civil, 1927, vol. 91; July 9, pp. 38-43; July 16, pp. 60-62; July 23, pp. 86-89). Alloy steels submitted to cementation by nitrogen show increases in hardness, particularly in the case of chromium-tungsten-vanadium steels, pearlitic and martensitic-vanadium steels, and nickel-manganese steels. The presence of vanadium, especially in nickel steels, has an important influence. The nitrogen is present probably as a complex nitride, which has its highest concentration at the surface of the metal. Steels cemented with

nitrogen are attacked by acids, alkalis, and salt solutions. Reference is made to the researches of Fry.

P. J. Haler, *Distortion Difficulties in Case-Hardening* (American Machinist, European Edition, 1927, vol. 67, Oct. 1, pp. 88E-89F). The author describes how the manner in which the quenching for hardening is carried out may cause distortion of the material.

Surface Decarburisation of Steel.—E. H. Schulz and W. Hülsbruch, *Surface Decarburisation of Carbon Steels* (Archiv für das Eisenhüttenwesen, 1927, vol. 1, Sept., pp. 225-240). Tests were carried out on the surface decarburisation of carbon steels, with special reference to scaling as dependent on the temperature, the carbon content of the steel, the annealing atmosphere, and in some cases the time. It appeared that decarburisation occurs in practically all gases and gas mixtures which are not carburising. Pure nitrogen and very careful packing in cast-iron turnings can be described as practically non-decarburising. Only methane-hydrogen mixtures are completely neutral. In gases consisting mainly of hydrogen or nitrogen, very small traces of CO₂, steam, and oxygen suffice to give rise to marked decarburisation. The atmospheres employed were classified into four groups (up to 900° C.), and decarburisation occurred in them on gradually increasing the temperature. The depth of decarburisation increases with the temperature. The effects of carbon and temperature on the depth and on the microstructure were examined, but the influence of the pearlite form could not be established. A layer of scale forms and protects the steel up to about 850°. The influence of carbon content on the thickness of the layer of scale was not observable.

Heat-Treatment Plant.—S. Tour, *Molten Baths for Heat Treating* (Fuels and Furnaces, 1927, vol. 5, Sept., pp. 1165-1174, 1188). The author deals with the development and applications of salt baths for heat treatment.

R. Sylvany, *Application of Continuous Tunnel Furnaces to Metallurgy* (Revue de Métallurgie, Mémoires, 1927, vol. 24, May, pp. 278-292). The author briefly reviews the advantages of this type of furnace, and then describes the annealing of thin sheets and the heat treatment of malleable iron castings as carried out in continuous tunnel furnaces by various American companies. In the latter connection the Dressler furnace is described.

F. Wintermeyer, *The Development of Electric Annealing and Hardening Furnaces* (Centralblatt der Hütten und Walzwerke, vol. 31, pp. 162-164). The author describes different types of electric heat-treatment furnaces, and discusses the advantages of electric heating.

Rotary Hearth Furnace for Annealing, Case-Hardening, &c. (Fuel Economist, 1927, vol. 2, Sept., pp. 633-635). In the furnaces described the hearth is mounted on rollers and rotated by means of an electrically driven worm-gear. They are gas fired, and specially adapted for all

classes of steel whether straight carbon or alloy steels, and have proved to be ideal for open annealing of all classes of material.

I. S. Wishoski, *Electric Furnaces of Interesting Design Used in Heat Treatment of Gears* (Fuels and Furnaces, 1927, vol. 5, Aug., pp. 991-995). The constructional details and mode of operation of electrically heated furnaces of the roller hearth type are described.

O. C. Trautman, *Automatic Heat Treatment of Springs in Electric Furnaces* (Fuels and Furnaces, 1927, vol. 5, July, pp. 895-897). *Electric Roller Hearth Furnace* (Forging, Stamping, Heat Treating, 1927, vol. 13, Apr., pp. 142-143). The author describes the design and operation of a continuous electric roller hearth furnace for the heat treatment of springs. In this type of furnace the heat-treating operation is entirely automatic from the time the work is placed on the trays until it is discharged from the quenching tank conveyor.

I. S. Wishoski, *Electric Furnace Used in Annealing Cylinders for Air-Cooled Engines* (Fuels and Furnaces, 1927, vol. 5, Sept., pp. 1199-1202). The author describes the operation of an electric furnace of the recuperative return type with automatically operated pusher, which has proved very efficient in annealing automobile engine cylinders. The material enters the heating chamber through a recuperative hood following along one line, and in the heating chamber it is transferred to another line, so that the annealed material is discharged through the same hood in a parallel line, the outgoing material preheating the material entering the furnace.

Heat Treatment of Automobile Springs in Electric Furnace (Fuels and Furnaces, 1927, vol. 5, Sept., pp. 1213-1214). Brief particulars are given of an electrically heated pusher type furnace through which the springs are carried through the heating chamber on a conveyor consisting of short tubes arranged in four parallel channels. The furnace is heated by banks of resistors situated above and below the hearth.

Continuous Furnace Used to Anneal Steel Castings (Iron Age, 1927, vol. 119, June 30, p. 1897). Brief particulars are given of a continuous annealing furnace of the gas-fired rotary type recently placed in operation at the plant of the Detroit Steel Castings Co., Detroit. The castings annealed in the furnace are stated to be remarkably free from scale.

H. F. Wood, *Automatic Electric Furnace: Its Uses and Possibilities* (Transactions of the American Society for Steel Treating, 1927, vol. 11, June, pp. 975-985). The author describes two rotary hearth electric furnaces for the heat treatment of automobile crankshafts. They are fitted with automatic charging and discharging devices, automatic quenching mechanism and transfer conveyors. The advantages and uses of this type of furnace are outlined.

A. Pomp, *Experiences with Electrical Bright Annealing Furnaces* (Iron and Steel Engineer, 1927, vol. 4, Aug., pp. 377-379). Various types of electric furnaces for bright annealing are briefly described.

E. Schreiber, *Tests with an Electrical Bright Annealing Furnace* (Iron and Steel Engineer, 1927, vol. 4, Aug., pp. 379-380).

A Continuous System of Bright Annealing (Iron and Coal Trades Review, 1927, vol. 115, July 29, p. 161). Brief particulars are given of a gas-fired continuous furnace for the bright annealing of steel stampings at 900° C. The furnace atmosphere is kept inert by the use of the Speck bright-annealing compound, but the nature of this is not disclosed in the article.

H. Repky, *Heat Transmission in Annealing Furnaces with Firebrick Muffles* (Archiv für Wärmewirtschaft, 1927, vol. 8, Apr., pp. 101-105).

E. F. Ross, *New Heat-Treating Furnaces Facilitate Production of High Strength Cap Screws* (Iron Trade Review, 1927, vol. 81, Sept. 8, pp. 588-591). A detailed account is given of the design and operation of a special type of automatic continuous gas-fired furnace for the heat treatment of cap screws. The furnaces are of the moving hearth type, and are in operation at an American plant, three furnaces being used for hardening and four for tempering. The units are similar in design except as to minor details. An interesting feature of each furnace is the conveyor belt, which is of stainless iron. The belt rests directly on the hearth of the furnace, and is made to move at a given rate by a small motor mounted on top of the furnace and connected to a pulley. Of the three hardening furnaces, two are equipped with oil-quenching tanks and one with a water-tank. All the furnaces are equipped with automatic temperature control which operates within limits of + or - 5 degrees.

E. Sheldon, *Heat-Treating at Brown and Sharpe's* (American Machinist, European Edition, 1927, vol. 66, June 4, pp. 679-682; June 11, pp. 737-739). The heat-treatment department of the Brown and Sharpe Manufacturing Co. is described. It is divided into two sections: one handles high-speed steel only; the other deals with carbon steels.

C. Longenecker, *Willys-Overland Forge and Treating Shop* (Forging, Stamping, Heat Treating, 1927, vol. 13, Sept., pp. 355-359). The new forge and heat-treating shops of the Willys-Overland Co., at Toledo, are described.

C. Longenecker, *Dodge Forge and Heat-Treating Plant* (Blast-Furnace and Steel Plant, 1927, vol. 15, Aug., pp. 385-395). A full description of the works of the Dodge Motor Corporation at Detroit. Details are also given of the mechanical and heat treatments applied to the various materials employed in the manufacture of automobile parts.

Pyrometry.—H. Schmidt, *The Measurement of Gas Temperatures* (Mitteilungen aus dem Kaiser-Wilhelm-Institut für Eisenforschung, 1927, vol. 9, pp. 227-238). The author describes a new method of measuring gas temperatures and an industrial gas pyrometer, which has shown its value in many branches of industrial practice, as in

muffles, waste-gas flues, cupolas, continuous furnaces, gas-producers, bag-houses, and boilers. The high accuracy of this method and the simple manipulation with a small expenditure of materials make the exact determination of gas temperatures easy, as compared with the inaccuracies of the ordinary thermocouple and the indications of the suction pyrometer.

W. Rohn, *Metals and Alloys for Thermo-Elements for the Measurement of High Temperatures* (Zeitschrift für Metallkunde, 1927, vol. 19, Apr., pp. 138-144). The author discusses the properties of the elements and of various alloys in relation to their use in thermocouples. He deals with both noble and base metal elements, the interchangeability of base metal alloys, base metal alloys with temperature scales similar to those of platinum/platinum-rhodium elements, the temperature compensation of the cold junction, and sheaths.

The Process of the Measurement of Temperature with Thermo-Elements (Zeitschrift für Metallkunde, 1927, vol. 19, Apr., pp. 144-148). The article describes the direct and indirect measurement of the e.m.f. of thermo-elements, their sources of error, and the degree of precision attainable.

J. Cournot, *Recent Progress in Pyrometry* (Chaleur et Industrie, 1927, vol. 8, June, pp. 317-323).

The Pyro Total Radiation Pyrometer (Génie Civil, 1927, vol. 91, Oct. 29, p. 447). In this pyrometer the radiant heat is focused on to a thermocouple enclosed in an evacuated bulb by means of a quartz lens.

Heat Treatment of Iron and Steel.—L. Traeger, *The Phenomena accompanying the Annealing of Hardened Steels* (Zeitschrift des Vereines deutscher Ingenieure, 1927, vol. 71, June 18, pp. 891-894). By means of measurement of changes in length of hardened carbon steels on annealing, it is shown that the annealing process proceeds in three separate stages, which begin respectively at about 100°, 235°, and 275° C. By following the annealing process throughout its course, it is obvious that the steel undergoes transformations at these points. A study of the changes in other properties leads to the theory that on annealing martensite and austenite, passing through an intermediate phase ζ , which has distinctive characteristics, change into α -iron and iron carbide. A study of these changes on annealing affords some indication of the proper heat treatment of steels.

S. P. Rockwell, *The Dilatometer for Heat Treatment* (Forging, Stamping, Heat Treatment, 1927, vol. 13, Apr., pp. 132-133, 150). The author explains the application and operation of the Rockwell dilatometer.

A. Portevin and A. Sourdillon, *Contribution to the Study of the Deformations accompanying the Heat Treatment of Steel* (Revue de Métallurgie, Mémoires, 1927, vol. 24, Apr., pp. 215-233). The authors deal specifically with those changes of dimension and form which

arise out of quenching, and heat treatment in general; included in the study is an examination of the formation of internal fissures and cracks and of the setting up of internal stresses. Except the first, all these phenomena are due to the aniso-thermal conditions existing in the specimen during cooling. Inequalities of temperature in the cooling mass cause geometrical deformations when they occur at high temperatures, and stresses—and consequently fissures—at low temperatures; the boundary between these two ranges lies at 500°–600° C. Repetition of any treatment giving rise to a given deformation will cause the amount of the deformation to increase.

Y. Chu-Phay, *On Grain Growth in Mild Steels* (Transactions of the American Society for Steel Treating, 1927, vol. 12, Oct., pp. 601–621, 688). New data are presented on the grain growth of ferrite in mild steels (0.10 per cent. carbon) upon annealing. The nature and possible cause of the differences in the results of previous investigators are discussed.

The author proposes a theory of grain growth in mild steels, based on the hypothesis that a boundary film exists, in which the carbide is colloiddally dispersed, and he discusses the relation of the boundary film to the structural changes in steel upon annealing. He also presents certain inferential evidence supporting the hypothesis. Other experiments predicated on the theory are shown to yield consistent results that may be interpreted only as a strong substantiation of the hypothesis. A slight age-hardening in the steel under investigation is noted and discussed.

A method of producing coarse grains by holding the steel sample above A_3 for a certain length of time, and then controlling the rate of cooling through the upper critical range, is described and discussed. Experimental evidence indicating the probable relation of germination (Sauveur's type) to the presence of the boundary film in mild steels is presented, but no definite explanation is offered.

J. H. Whiteley, *Hair Cracks in Steel Rails* (Transactions of the American Society for Steel Treating, 1927, vol. 12, Aug., pp. 208–220, 234). The author gives the results of an examination of a number of basic steel rails, which had been sorbitised during manufacture. On straightening, many of the rails broke in two, showing the presence of a grey spot in the crystalline fracture. Two methods were employed in the examination of this defect: the method of Rawdon, consisting of magnetisation and treatment with iron dust in kerosene, and the effect of a reagent. It is inferred that the steel contained numerous minute cavities filled with gas under high pressure. Further, it is believed that the pressure was due, in part, to the rapid cooling in sorbitising, for there would be then less opportunity than in normal cooling for the gases to escape by diffusion through the surrounding walls. As a result, severe stresses would develop in the immediate vicinity of the cavities. In this way local incipient cracks might be formed by rupture along adjacent grain boundaries. The large

proportion of CO found in the gases liberated from the cavities suggests that they are a result of an interaction between the oxide of iron and the carbon in the steel during rolling. That the steel had been over-oxidised was certainly indicated by the amounts of silicates present. Moreover, it has been found that those conditions of working which tend to keep the oxide content of the bath at a minimum favour the production of sorbitised rails free from hair cracks.

O. Pilz, *Methods of Improving Rail Material* (Stahl und Eisen, 1927, vol. 47, Oct. 6, pp. 1645-1651). The various means employed to improve rails by alteration in chemical composition or heat treatment are described, with special reference to the Sandberg, Neuves-Maison, Ruhrort-Meiderich, and Maximilianshütte processes. Results of tests on rails treated by these processes are given and criticised. No works has at present a plant capable of dealing with the whole of its output by any of these processes.

E. Marcotte, *The Sorbitic Treatment of Wheel Tyres for Railway and Tramway Vehicles* (Génie Civil, 1927, vol. 91, Oct. 22, pp. 411-412). The author enumerates the advantages of the sorbitic structure for wheel tyres, and mentions the Sandberg process for rendering tyres sorbitic.

L. Thibaudier and H. Viteaux, *The Question of Steel for Rails and the Heat Treatment at the Neuves-Maison Works* (Revue de Métallurgie, Mémoires, 1926, vol. 23, Feb., pp. 65-81; abstract, Iron Age, 1927, vol. 120, Aug. 11, pp. 337-338).

E. Marcotte and Martineau, *New Thermal Treatments of Rail Steel* (Revue de Métallurgie, Mémoires, 1927, vol. 24, Jan., pp. 10-19; Feb., pp. 68-78; abstracts, Metallurgist, 1927, July 29, pp. 104-105; Journ. I. and S.I., 1927, No. I. p. 899).

F. W. Duesing, *The Heat Treatment of Structural Steels* (Zeitschrift des Vereines Deutscher Ingenieure, 1927, vol. 71, Feb. 26, pp. 297-300). Tests were made on ordinary structural steels to determine the tensile properties, impact resistance, and Brinell hardness of the steels, after annealing at various temperatures, and quenching in oil and in water. The results are shown clearly in diagrams and curves.

E. Maurer, *Heat Stresses on Cooling Large Castings or on Treating Cylindrical Forgings* (Stahl und Eisen, 1927, vol. 47, Aug. 11, pp. 1323-1327). An attempt is made to calculate the heat stresses on cooling and treating large castings or on treating large cylindrical forgings. It is shown that the calculated figures must lie below the stresses really present. The influence of tempering on these stresses and the importance of the elastic limit at the tempering temperature are discussed.

Heat Treatment Eliminates Wheel Failures (Electric Railway Journal, 1927, vol. 70, July, pp. 93-95). A method is described of hardening and tempering rolled steel car wheels which has been developed by the Twin City Rapid Transit Co. The method has resulted in the elimination of failures and a reduction in wear of wheels.

B. Kjerrman, *Heat Treatment of Two Ball-Bearing Steels* (Transactions of the American Society for Steel Treating, 1927, vol. 12, Nov., pp. 759-777). The author gives the results of electrical resistance tests on two ball-bearing steels, one of the common type and one with a higher chromium content and the addition of molybdenum. The Ac_1 interval for the two steels was the same, between 1362° and 1387° F. (739° and 753° C.). By means of electrical resistance measurements at constant temperature on quenched specimens it is shown that it is possible to determine the percentage of alloying elements which is effective in hardening the steel. On the basis of Benedicks' formula it is possible to determine a percentage of efficiency for the different steels. It is shown that this percentage of efficiency will be lowered by the addition of too great an amount of alloying elements or by too high a percentage of carbon, due to the fact that the alloying elements have the ability to form stable carbides at temperatures above the Ac_1 interval. It should be possible by means of this method to eliminate several of the now complicated analyses of steels and to obtain a considerably cheaper steel while maintaining the standard in mechanical properties.

W. Haufe, *The Influence of Silicon, Nickel, Chromium, and Tungsten on the Hardening of Tool Steels* (Stahl und Eisen, 1927, vol. 47, Aug. 18, pp. 1365-1373). The influence of additions of silicon, manganese, nickel, chromium, and tungsten on the tendency of tool steel to crack on hardening, on the increase in volume, and on the fracture of a hypereutectoid steel, are investigated. The more important results are as follows: (1) On increasing the silicon content, a hypereutectoid steel shows a tendency to crack on quenching from high temperatures. The fracture is, however, quite good even after quenching from 930° , and the tendency to hardness cracking can therefore be avoided by oil-hardening. (2) The hardening range of hypereutectoid steel is greatly reduced by increasing manganese, *i.e.* the steel is more sensitive to cracking when quenched from the temperatures currently employed. (3) Hypoeutectoid steel with sufficient silicon and manganese behaves, at the lower limit of the hardening range (780°), as hypereutectoid carbon steel, and, at the upper limit (830°) rather better than eutectoid carbon steel. (4) Nickel additions hardly affect the hardening properties of hypereutectoid steel. (5) Chromium additions up to 1 per cent. make a hypereutectoid steel considerably less sensitive to cracking on hardening. With 1.2 per cent. chromium the penetration of hardening is increased very considerably, without any reduction in the toughness of the outer layer. With 1.5 to 2.0 per cent. chromium the fractures are still good, even after quenching from 930° , so that cracking can be avoided by oil-hardening, as with silicon additions. Silicon-chromium steels are worthy of more attention than has been given them, as, with sufficient chromium, the change in dimensions on quenching are probably very insignificant. (6) No conclusions could be drawn as to tungsten steels on account of precipitation of the carbide on soft annealing.

L. C. Miller, *The Heat Treatment of Various Steels* (Forging, Stamping, Heat Treating, 1927, vol. 13, Sept., pp. 362-365). A discussion of the effects of various alloying elements on the method of heat treatment and resultant physical properties of steels.

A. Schleicher, *On the Formation of Ferrite and the Reduction of the Impact Resistance of Reconditioned Nickel-Chrome Steels* (Revue de Métallurgie, Mémoires, 1927, vol. 24, May, pp. 293-295). In the case of samples imperfectly normalised in the works, the author shows how badly affected is the texture of chrome-nickel steels by the use of too high temperatures for forging and annealing and by too long a period of annealing; as a result the resistance to impact is also badly affected. He points out the difference between the needle-like structure of the ferrite and the Widmannstätten structure. The relation to the appearance of temper brittleness is briefly referred to.

B. Egeberg, *A Neglected Phenomenon in Heat Treatment* (Transactions of the American Society for Steel Treating, 1927, vol. 12, July, pp. 46-50). Quenching temperature is generally determined in relation to the critical point in heating. This method is justified in cases where the Ac and Ar points are close together. Many chromium-nickel steels, however, show a considerable difference between the critical points, and it is believed that this fact is not generally considered. By quenching a piece of steel, in which there is considerable difference between the Ac and Ar points, at a temperature closer to the Ar point rather than the Ac point, the advantages of the lower quenching temperature are gained. Maximum hardness and tensile strength with suitable elongation are obtained, and it is believed that less dimensional change takes place and that hardening cracks may be eliminated.

H. C. Knerr, *Heat Treatment and Metallography of Steel* (Forging, Stamping, Heat Treating, 1927, vol. 13, June, pp. 237-240; Sept., pp. 379-381). The continuation of a serial (see Journ. I. and S.I., 1927, No. I. p. 899). In the present chapters quenching and temperature and atmospheric control in the furnaces, are discussed, and some practical hints are given.

T. Matsushita and K. Nagasawa, *The Mechanism of Tempering of Steels* (Paper read before the Iron and Steel Institute, Sept. 1927: this Journal, p. 311).

T. Matsushita and K. Nagasawa, *On the Phenomenon of Temper-Hardening in Steels* (Science Reports of the Tōhoku Imperial University, Sendai, 1927, vol. 16, pp. 639-653; see also Journ. I. and S.I., 1927, No. I. p. 731).

J. W. Harsch, *The Hump Method of Heat Treatment* (Forging, Stamping, Heat Treating, 1927, vol. 13, Sept., pp. 372-373); *Development in Heat Treatment* (Machinery, 1927, vol. 30, July 7, pp. 435-437). *The Hump Method of Hardening* (Automobile Engineer, 1927, vol. 17, Aug., pp. 304-305). The "hump" method of controlling the temperature to which articles intended to be quenched shall be

heated is explained. The Homo furnace is described; rapid heat absorption is attained by circulating the air in the furnace by means of a fan, and the transfer of heat by radiation is claimed to be practically eliminated.

G. M. Eaton, *Design from the Heat Treating Standpoint* (Transactions of the American Society for Steel Treating, 1927, vol. 12, Nov., pp. 794-813). The author stresses the need for closer co-operation between the metallurgist and the mechanical engineer. The design of springs and gears is discussed from the point of view of the heat treater, and stress distribution in heat-treated parts is also considered.

H. B. Knowlton, *Effects and Principles Concerning Steel and Heat Treatment.—Part XIII.* (Transactions of the American Society for Steel Treating, 1927, vol. 12, July, pp. 106-125). The author discusses the effects of manganese in simple steels and the composition, properties, and uses of various types of manganese steels. Charts are presented, showing the physical properties of some of the pearlitic manganese steels.

H. B. Knowlton, *Facts and Principles Concerning Steel and Heat Treatment.—Part XIV.* (Transactions of the American Society for Steel Treating, 1927, vol. 12, Sept., pp. 479-491). This paper deals with the use of vanadium in various types of steels, and heat treatments, properties, and uses are described.

H. B. Knowlton, *Facts and Principles Concerning Steel and Heat Treatment.—Part XV.* (Transactions of the American Society for Steel Treating, 1927, vol. 12, Nov., pp. 814-826). The properties and uses of specific types of chromium-molybdenum, nickel-molybdenum, and chromium-nickel-molybdenum steels are briefly discussed.

E. Ryd, *The Heat Treatment of Steel* (Teknisk Tidskrift (Mekanik) 1927, vol. 57, Apr. 16, pp. 52-54). A report on German practice in the heat treatment of steel.

S. G. Williams, *Metals and Their Heat Treatment* (Journal of the Royal Aeronautical Society, 1927, vol. 31, June, pp. 602-613). The author discusses the heat treatment of alloy steels and light alloys.

E. F. Davis, *Annealing and its Importance in Steel Treating* (Iron Trade Review, 1927, vol. 80, June 23, pp. 1589-1592). A discussion of the annealing of steel to improve its machinability.

J. W. Urquhart, *Pitfalls in Heat Treatment* (Machinery, 1927, vol. 30, Aug. 25, pp. 658-659). The author reviews the many ways in which heat-treated work may be spoiled.

Report of Committee A4 on Heat Treatment of Iron and Steel (American Society for Testing Materials, June 1927). The proposed definitions of terms relating to heat treatment operations drawn up by the American Society for Testing Materials, the Society of Automotive Engineers, and the American Society for Steel Treating are presented.

E. H. McClelland, *Books on the Heat Treatment of Steel* (Forging, Stamping, Heat Treating, 1927, vol. 13, Sept., pp. 369-371). A

bibliography of English, French, and German books on this subject, most of them modern.

Welding.—J. F. Lincoln, *Arc Welding* (Paper read before the American Society of Mechanical Engineers, May 23–26, 1927: *Mechanical Engineering*, 1927, vol. 49, Mid-May, pp. 558–560). The author discusses the advantages of arc-welded steel parts over those of cast iron or riveted construction, and the saving that may be effected by replacing the latter by the former. He points out the inconsistency of permitting arc-welding in superheaters and steam piping and forbidding it in boilers, &c.

J. M. Vossler, *The Electric-Arc Process in Repairing Cylinders* (*American Machinist*, European Edition, 1927, vol. 67, Oct. 8, pp. 335–338). The author describes the arc-welding of grey cast iron cylinders, and explains the reasons for the various precautions taken. In making a weld with steel on cast iron it is preferable that the actual junctions between the cast iron and steel (which are composed of a brittle mixture of iron and steel) should be in shear rather than in tension.

E. Höhn, *Electrically Welded Reinforcing Straps on Boilers and Containers* (*Mechanical Engineering*, 1927, vol. 49, July, pp. 731–734). The particulars recorded here regarding early investigations conducted in Switzerland are contributed by the author as a supplement to an earlier article (see *Journ. I. and S.I.*, 1926, No. II. p. 609).

J. F. Lincoln, *Electric Welding of Pipes* (*Journal of the American Institute of Electrical Engineers*, 1927, vol. 46, June, pp. 593–596). The author points out the advantages of arc welding for the manufacture of pipe.

J. L. Avis, *Suggests Annealing for Welded Pipe* (*Iron Age*, 1927, vol. 120, Aug. 25, pp. 474–476). The author briefly outlines a method of manufacturing electric arc-welded steel pipes, and presents typical results of tension tests on welded specimens which show that the welding process reduces the strength and ductility of the original plate. The advantages of annealing are pointed out.

J. H. Edwards, *Application of Welding to a Steel Structure* (Paper read before the American Iron and Steel Institute, May 1927). The author gives details of the design, fabrication, erection, and cost of an all-welded five-storey building erected at Sharon, Pa. Based on the experience gained from this work, it would seem that the all-welded skeleton structure is not the most economic one. It is possible that some parts of such a structure might be welded to advantage. By the fusion welding process joints can be made as strong as the base metal, and the full gross section of a tension member can be used, with no deduction for holes as when rivets are used. Due to the greater stiffness of end connections, and the ease with which component parts can be more rigidly held together, welded details of compression members increase their efficiency. By taking advantage of

these favourable factors, and with the added advantage that will obtain when sections more suited to welding are rolled, there may be some saving in material that will more than offset the extra cost of welding.

H. Schottky, *Fusion Welding and Fracture Due to Fatigue* (Kruppsche Monatshefte, 1926, vol. 7, Dec., pp. 213-216; *abstracts*, Metallurgist, 1927, Apr. 29, p. 64; Journ. I. and S.I., 1927, No. I. p. 912).

Pothmann, *Melting Flames, Particularly the Acetylene Welding Flame* (Autogene Metallbearbeitung, 1927, vol. 20, Feb. 15, pp. 50-57; Mar. 1, pp. 67-73). Experimental data on relation between speed of welding to thickness of plate and properties of metal, effect of oxygen content, presence of water vapour and other injurious gases, chemical composition of acetylene and oxyacetylene flames and their structure; heat value of acetylene and many other gas and liquid flames which may be employed in welding.

H. E. Rockfeller, *Oxyacetylene-Welded Construction of a Large High-Pressure Storage Tank* (Paper read before a joint meeting of the American Society of Mechanical Engineers and the American Welding Society, Jan. 4, 1927: Mechanical Engineering, 1927, vol. 49, May, pp. 405-411). The author describes the procedure involved in the construction of welded pressure vessels.

Thermit Welding in the Steel Mills (Blast-Furnace and Steel Plant, 1927, vol. 15, Aug., p. 402). The article describes the advantages and economies made possible by a new method of making thermit welds, but no details of the method itself are given.

H. Lotze, *Aluminium Thermit Welding of Rail Joints on the Berlin Rapid Transit* (Verkehrstechnik, 1927, vol. 40, Mar. 4, pp. 138-139). The author outlines the extent and conditions of aluminium thermit joint welding on the Berlin Underground Railway.

To Weld Manganese Steel (Iron and Steel of Canada, 1927, vol. 10, Apr., p. 115). As the desirable properties of manganese steel are developed by a proper heat treatment, welding becomes a difficult matter, and it is shown that for satisfactory results the work must be preheated and heat treatment again is necessary after the welding is completed.

H. Y. Carson, *Describes Further Developments in Bronze Welding Cast-Iron Pipe* (Paper read before the American Water Works Association: Foundry, 1927, vol. 55, Oct. 1, pp. 763-764). A brief outline of the procedure to be followed in the welding of cast-iron pipe with bronze.

H. Dustin and D. Rosenthal, *A Rational Calculation of the Elements in Welded Constructions* (Paper read before the International Testing Congress, Amsterdam, 1927).

P. L. Roberts, *The Welding of Cast Iron* (Welding Journal, 1927, vol. 24, Mar., pp. 70-76).

R. R. Moore, *Fatigue of Welds* (Journal of the American Welding Society, 1927, vol. 6, Apr., pp. 11-32).

A. Sonderegger, *Status of the Art of Welding—Its Problems and Aims* (Paper read before the International Testing Congress, Amsterdam, 1927).

W. L. Warner, *Replacing Castings with Structural Shapes* (Paper read before the American Welding Society, Jan. 4, 1927: Forging, Stamping, Heat Treating, 1927, vol. 13, May, pp. 196–197). The author discusses the advantages of welded rolled steel sections over cast iron.

Welded Parts Take the Place of Castings (Machinery, 1927, vol. 30, Sept. 8, pp. 713–717). The advantages of welded structures over castings are enumerated, and methods of manufacture are illustrated and described. Examples are given, and oxy-coal gas and special welding machines are also reproduced and noted.

W. Strelow, *Welding and Riveting Compared as to Economy* (Maschinenbau, 1927, vol. 6, June 2, pp. 549–553; June 16, pp. 610–614; July 1, pp. 664–666). Much information is given by means of graphs of time and costs analyses of riveting and welding based on German practice.

I. Langmuir, *Flames of Atomic Hydrogen* (Industrial and Engineering Chemistry, 1927, vol. 19, June, pp. 667–674). The author treats of the physical and chemical properties of atomic hydrogen, use of which is made in the atomic hydrogen welding torch.

Miscellaneous Products.—J. D. Knox, *Pipe and Tube Production is Confined to Nine States* (Iron Trade Review, 1927, vol. 81, July 21, pp. 134–137). Particulars concerning the location, number, capacity, and range of the pipe and tube manufacturing concerns in the United States are tabulated. Over 60 per cent. of the butt-welded pipe mills, 83 per cent. of the lap-welded pipe mills, and 90 per cent. of the seamless tube mills are situated in Ohio and Pennsylvania.

G. Ferrand, “*Corrugated*” *Hooped Tubes* (Arts et Métiers, 1927, vol. 80, June, pp. 197–199). These pipes are claimed to give very great strength with lightness. A very mild steel tube is formed in one of the usual ways, and a number of hoops forged from the solid are placed round it at suitable intervals. Hydraulic pressure is applied internally, and the tube expands to fit the hoops tightly, those portions between the hoops becoming slightly “bulged.” The hydraulic pressure is generally two and a half times as great as the working pressure for which the tube is designed; this then constitutes a good test of the material. The metal is stressed beyond the elastic limit, hence the deformations produced are permanent.

M. A. Hall, *Woven Wire Netting* (Wire, 1927, vol. 2, July, pp. 239–242, 248). The manufacture of wire netting, and the weaving press, are described.

J. E. Thompson, *The Manufacture of Wire and Wire Ropes* (Mechanical World, 1927, vol. 81, Feb. 11, pp. 99–100; Feb. 18, pp. 120–121).

P. Siebe, *Annealing Experiments with Various Metal Wires* (Zeitschrift für Metallkunde, 1927, vol. 19, Oct., pp. 385-389). Experiments on annealing in the salt bath were carried out on wires of various metals, including open-hearth steel. The influence of the temperature and time of annealing on the softening, and the shortest time required for softening of the wires, were determined.

G. A. Richardson, *Great Industrial Economies Profitable in Plants of the Bethlehem Steel Co.* (Proceedings of the Central Railway Club, Buffalo, 1927, vol. 35, Apr., pp. 2303-2307). The manufacture, machining, and inspection of solid rolled steel car wheels are discussed.

PHYSICAL AND CHEMICAL PROPERTIES.

Properties and Tests of Cast Iron.—P. Bardenheuer, *Graphite in Grey Iron* (Mitteilungen aus dem Kaiser-Wilhelm-Institut für Eisenforschung, 1927, vol. 9, pp. 215–225; Stahl und Eisen, 1927, vol. 47, May 26, pp. 857–867). The proportion of graphite in cast iron is usually about 3, rarely less than 2, per cent. The disturbing effect of this amount can be better appreciated by expressing it as a volume percentage instead of a weight percentage. Taking the specific gravity of cast iron as 7.3 and that of graphite as 2.1, then $\frac{1}{3}$ per cent. of graphite by weight corresponds to about 3.5 per cent. by volume, so that a cast iron with 2.5 per cent. graphite by weight contains a volume percentage of 8.7. The form of the graphite is dependent upon the conditions under which the precipitation occurs; in this respect it is of importance whether the crystallisation of the graphite eutectic occurs in a melt free from nuclei or whether it is initiated by graphite remaining undissolved. Experiments show that the distribution and form of the graphite have a powerful effect on the strength of the metal, stronger, indeed, than that due to the structure of the metallic ground-mass. A comparison of the older and later attempts to improve the quality of grey cast iron shows that all the methods tried, which gave results at all, were directed in the first place towards the production of a satisfactory distribution of the graphite.

G. Neumann, *Strength and Structure of Cast Iron* (Stahl und Eisen, 1927, vol. 47, Sept. 29, pp. 1606–1609). Bardenheuer's results on the fundamental influence of graphite on the strength of grey irons are confirmed by treating and annealing tests on grey cast-iron bars. The strength of the ground-mass is most evident in its effect on hardness; in tensile tests it is masked by the influence of graphite. Lowest possible graphite content in the finest possible flakes is to be aimed at; the properties of the ground-mass are of secondary importance. The effect of the ground-mass could not be detected in the actual materials tested as the graphite was coarse.

E. Diepschlag, *Influence of Carbon on the Properties of Cast Iron* (Giesserei Zeitung, 1927, vol. 24, Aug. 1, pp. 418–420). In cast iron carbon occurs as elementary and as combined carbon. The cause of the formation of these two types, the control of their relative proportions by means of alloying or by thermal treatment, and the relation of the type of carbon occurrence to the mechanical properties of the metal, are discussed.

J. W. Bolton, *Some Graphite Formations in Grey Cast Iron* (Paper read before the American Foundrymen's Association, June 1927).

The author discusses the various formations of graphite found in cast iron and the cause of such formations. The five following forms are recognised: (a) The broad, straight flake; (b) the rosette or whorl; (c) the dendritic striation; (d) the grouped formation, consisting of clear dendritic lakes, the peninsulas being filled with fine graphite flakes; and (e) the rounded temper carbon. The importance of microscopic examination is stressed and the three-dimensional conception is emphasised. A special section in the paper is devoted to the distribution of graphite, and the factors affecting it are fully described.

E. Schüz, *The Separation of Graphite from Grey Cast Iron* (Paper read before the International Foundry Congress, Paris, 1927). The author discusses the separation of carbon in the form of eutectic graphite.

H. Hanemann, *The Effect of Graphite on Structure of Grey Cast Iron* (Centralblatt der Hütten und Walzwerke, 1927, vol. 31, May 25, pp. 273-275).

F. T. Sisco, *The Constitution of Steel and Cast Iron.—Part IX.* (Transactions of the American Society for Steel Treating, 1927, vol. 11, June, pp. 986-996). The formation of graphite in cast iron is discussed, and typical structures of grey iron containing graphite are shown.

F. T. Sisco, *The Constitution of Iron and Steel.—Part X.* (Transactions of the American Society for Steel Treating, 1927, vol. 12, Aug., pp. 279-290). A discussion of the effect of silicon, sulphur, phosphorus, and manganese on iron-carbon alloys containing 2 per cent. or more of carbon.

F. T. Sisco, *The Constitution of Steel and Cast Iron. Section II.—Part I.* (Transactions of the American Society for Steel Treating, 1927, vol. 12, Oct., pp. 651-666). The paper is an introduction to the study of the theory of heat treatment. The constitution of steel and cast iron is briefly reviewed from the standpoint of stable equilibrium, and the solid solution of carbon in γ -iron is discussed at length. The conflicting views of the internal structure of austenite are presented, and the grain growth of austenite above the critical range is discussed.

P. Ropsy, *Carbon in Cast Iron* (Foundry Trade Journal, 1927, vol. 36, Sept. 1, pp. 199-204). The influence of carbon on the constitution and properties of cast iron is reviewed.

E. L. Roth, *Effect of Heat Treatment on the Combined Carbon in Grey Cast Iron* (Transactions of the American Society for Steel Treating, 1927, vol. 12, July, pp. 27-40). The results are given of a series of experiments carried out to determine the effect of heat treatment on the combined carbon in grey cast iron. Samples with different carbon and silicon contents were used, heated to various temperatures. The maximum resolution of combined carbon in grey cast iron into graphitic carbon occurs at 1400° F., when the iron is heated for one-half to three hours. Microscopic examination shows that the formation of graphitic carbon is propagated from the edges toward the centre. From these experiments it is shown that silicon does not have a marked effect on

the graphitisation, although other investigators have shown that it materially aids graphitisation in white cast iron.

Le Thomas and Domanski, *A Curious Example of Thermal Treatment of Cast Iron* (Paper read before the International Foundry Congress, Paris, 1927). At the plant of Établissements d'Indret during the casting of a solid shaft, the mould gave way under pressure of the molten iron, forming a hollow in the casting, which was filled up with additional iron. An examination of the structure of the casting showed that the extreme slow cooling of the second iron had allowed the pearlite to assemble in broad bands at below 700° C. On the other hand, the contact of this second iron raised the temperature of the first iron and produced graphitisation. The structure of the first iron corresponded to that of the stable ferro-graphite system.

P. Oberhoffer and E. Piwowarsky, *Oxygen in Pig Iron and Cast Iron* (Stahl und Eisen, 1927, vol. 47, Mar. 31, pp. 521-533; abstract, Iron Age, 1927, vol. 120, July 14, pp. 75-76).

K. Honda and H. Endo, *On the Volume Change in Cast Iron during Solidification, with a Criticism of the Double Diagram of the Iron-Carbon System* (Science Reports of the Tôhoku Imperial University, Sendai, 1927, vol. 16, pp. 9-25). With the object of confirming the view that in the iron-carbon system the graphite formed during solidification is a decomposition product of cementite and not the product of a direct precipitation from the melt, the authors have measured the change of volume of different cast irons during solidification by means of a thermo-balance. The irons used in the experiments contained approximately the same amount of carbon, but the silicon content varied from 0.08 to 2.31 per cent. It was observed that as the graphitic carbon found in the solidified specimens decreased, the change of volume varied from a positive value to a negative. The contraction of volume in the case where no cementite decomposes was found to be 3.6 per cent. If it is admitted that the graphite present is a decomposition product of cementite, the volume change due to such decomposition can be calculated from the amount of graphite present, and hence the actual change of volume is found by the relation :

$$\frac{\delta v}{v} = -3.6 + \text{volume change due to decomposition (\%)}.$$

The coincidence between the observed and calculated values confirms the correctness of the view that graphite present in cast iron is the decomposition product of cementite precipitated from the melt at high temperature. Thus, if the graphite be a decomposition product of cementite, the double diagram of the iron-carbon system is not the correct representation of the observed facts.

The Influence and Condition of Sulphur in Cast Iron (Iron and Steel Industry, 1927, vol. 1, Nov., pp. 37-39). The older ideas concerning the bad influence of sulphur on cast iron are briefly set out, and the evidence to the contrary supplied by more recent researches is stated. The conclusion is drawn that the presence of sulphur is not necessarily

harmful to cast iron; the troubles frequently attributed to sulphur, such as blowholes, unsoundness, and segregation, cannot be directly or definitely traced to this element, and with careful attention to other details can be eliminated even in high-sulphur irons.

J. E. Fletcher, *The Strength of Cast Iron* (Paper read before the Institute of British Foundrymen: Foundry Trade Journal, 1927, vol. 36; July 21, pp. 69-72; July 28, pp. 89-92). The dominating influence of silicon and total carbon together, and the importance of the carbon and silicon proportions in the (T.C. + Si) factor must have first attention when attempting to interpret the analysis of a cast iron in terms of its mechanical strength. It is shown how many different compositions (in respect to total carbon and silicon contents) may be used in obtaining iron of given transverse rupture strength. The influence of total carbon, silicon, manganese, and phosphorus have been related to Brinell hardness values, and the importance of the sum of the total carbon and silicon contents is shown. The modulus of rupture or rupture stress in transverse tests, when considered in relationship to the ultimate tensile strength, yield a valuable factor, T_v/T , which plays an important part in the study of the strength of cast iron. This factor is related to the deflection, to the sum of the total carbon and silicon contents, and to the relationship of carbon to silicon in that sum.

P. Kleiber, *Krupp's Special Cast Iron (Sternguss)* (Kruppsche Monatshefte, 1927, vol. 8, June-July, pp. 109-116). The manufacture of castings of high quality has been developed, based on Maurer's diagram for cast iron, according to which the pearlitic structure strongly predominates in a low-carbon iron. The analysis of *Sternguss*, as the special metal is termed, is: total carbon 2.50-2.90, silicon 1.90-2.30, manganese 1-1.4, phosphorus 0.10-0.25, sulphur 0.08-0.13 per cent. The tensile strength measured on turned bars 15 mm. diameter is 25 tons per sq. in., the transverse strength of the machined bar is 38 tons, the deflection $\frac{1}{4}$ to $\frac{1}{2}$ in., and the permanent deflection $\frac{1}{16}$ - $\frac{1}{8}$ in. A number of micrographs illustrate the structure of the material.

C. H. Adamson and G. S. Bell, *Transverse and Other Tests on Cast-Iron Test-Bars* (Iron and Steel Institute: Carnegie Scholarship Memoirs, 1927, vol. 16, pp. 1-34). The work described in this memoir is an extension of the investigation by the same authors reported in a paper entitled "Transverse Test-Bars and Engineering Formulæ" (Journ. I. and S.I., 1924, No. I. pp. 347-361). The object was to discover how, under practical foundry conditions, transverse test values, calculated by the usually accepted engineering formulæ, compared with results actually obtained, and the present memoir records the experimental data of a large amount of work carried out after the publication of the original paper. The authors are of opinion that the engineering formulæ used in the memoir are, in the results they have obtained, insufficiently accurate to meet practical requirements in comparing tests on different sizes of bars, but that they are, on the whole, sufficient

for comparing tests on different centres for the same size of bar. The compression test was also investigated, and the results show that, as anticipated, the compression test varies in inverse ratio to the size of bar as cast. In other words, the more open the fracture, the lower the test. The impact test was examined, and a possible further field of research was indicated.

H. F. Moore and S. W. Lyon, *Tests of the Endurance of Grey Cast Iron Under Repeated Stress* (Paper read before the American Society for Testing Materials, June 1927). The authors present the results of tests on four lots of grey cast irons. The tests included tension, compression, Charpy impact, Brinell hardness, and rotating beam fatigue tests. A new form of tension test specimen was used which was designed to ensure a uniform distribution of stress across the critical cross-section. The fatigue tests showed a fairly well marked endurance limit for each of the cast irons, but in each case the endurance limit was low, and the ratio of endurance limit to tensile strength was lower than is usually found for steel. The fatigue strength of cast iron was markedly increased by oft-repeated stress below the endurance limit. Grooves in the cast-iron test specimens reduced the endurance limit by a small amount. A much larger percentage of reduction of endurance limit by a similar groove has been found in the case of test specimens of steel and of copper. Specimens of cast iron were tested under cycles of reversed flexure at temperatures ranging from room temperature to 760° C. No great reduction of endurance limit was found for temperatures below 425° C. Above about 650° C. the endurance limit was fully as high as was the tensile strength under prolonged steady load. Specimens tested under cycles of stress ranging from zero to a maximum gave an endurance limit 1.48 times the endurance limit for specimens tested under cycles of completely reversed flexural stress.

H. F. Moore and S. W. Lyon, *Fatigue Tests of Cast Iron* (Paper read before the American Foundrymen's Association, June 1927).

H. F. Moore, S. W. Lyon, and N. P. Inglis, *Tests of the Fatigue Strength of Cast Iron* (Illinois University: Engineering Experiment Station, 1927, Bulletin No. 164).

O. Schwarz, *A Practical Course in the Testing of Cast Iron* (Giesserei Zeitung, 1927, vol. 24, Aug. 15, pp. 441-446). The course of practical study was prepared by R. Baumann for the students of Stuttgart Technical High School, and proved highly successful. It included the carrying out and recording of results of tests to determine the tensile and compression strength of cast iron, the effect on a casting of repairing faulty spots, the machinability by means of drilling tests, the growth under repeated heatings, the effect of core supports on the structure and strength, and the effect of welding. The course is illustrated with diagrams and micrographs.

A. Portevin, *Mechanical Testing of Grey Iron Castings* (Paper read before the International Testing Congress, Amsterdam, 1927).

A. L. Norbury, *Tests for Cast Iron* (Paper read before the International Testing Congress, Amsterdam, 1927).

P. Herman and H. Henquin, *A Few Trial Methods and Properties of Various Grey Cast Irons* (Paper read before the International Foundry Congress, Paris, 1927).

O. H. Lehmann, *The Wear of Cast Iron under Sliding Friction* (Giesserei-Zeitung, 1926, vol. 23, Nov. 1, pp. 597-600; Nov. 15, pp. 623-627; Dec. 1, pp. 654-656; abstract, Foundry, 1927, vol. 55, Sept. 15, pp. 722-723).

E. Piwowarsky, *Comparative Wear Tests on Cast Irons of Various Phosphorus Content* (Paper read before the International Testing Congress, Amsterdam, 1927).

M. Girardet, *Simple and Rapid Method for the Control of Mechanical Properties of the Structure of Cast Iron* (Paper read before the International Foundry Congress, Paris, 1927).

W. Melle, *The Hardness and Machining Qualities of Cast Iron* (Giesserei-Zeitung, 1927, vol. 24, Sept. 1, pp. 485-492). The quality of the machinability of cast iron is defined by means of comparative tests made with the Kessner hardness drilling machine, and it was established that a definite relation exists between hardness H and machinability M according to the ratio: $M \times H^{1.47} = \text{constant}$. The exact conditions of the tests are recorded.

D. M. Houston, *Effect of Nickel on Machinability of Cast Iron* (American Machinist, European Edition, 1927, vol. 66, July 16, pp. 961-962). The author discusses the behaviour of the various elements which enter into the composition of cast iron and the manner in which they affect the machining properties. Nickel acts similarly to silicon in controlling the combined carbon, thus suppressing the formation of scale, softening the edges and corners, and dissolving the carbide spots, but, unlike silicon, it does not induce internal shrinkage. With nickel in an otherwise well-balanced mixture it is unnecessary to anneal before machining.

J. Galibourg, *The Use of Nickel in American Iron Foundries* (L'Usine, 1927, Apr. 23, p. 27). Experiments in the addition of nickel to cast iron have shown that nickel influences the density and the distribution of constituents. Cementite is transformed into ferrite and graphite, the graphite particles are refined, and the nickel goes into solution, changing pearlite into sorbite. Nickel increases the hardness of cast iron and raises the limit of elasticity, the tensile strength, and resistance to impact. The wear is greatly reduced in motor cylinders made of such material. Chromium has the opposite effect of nickel; it maintains the carbon as cementite, and is therefore a hardening element. Nickel can be added in the cupola and also in the ladle, and no loss of metal occurs in the cupola. Chromium, however, should only be added in the ladle. Nickel-chromium cast iron has been used with great success for cylinders of gas engines and petrol engines.

A. B. Everest, T. H. Turner, and D. Hanson, *The Influence of*

Nickel and Silicon on an Iron-Carbon Alloy (Paper read before the Iron and Steel Institute, Sept. 1927 : this Journal, p. 185).

D. Hanson, *The Constitution of Silicon-Carbon-Iron Alloys, and a New Theory of the Cast Irons* (Paper read before the Iron and Steel Institute, Sept. 1927 : this Journal, p. 129).

A. B. Everest, *The Influence of Aluminium on an Iron-Carbon Alloy* (Foundry Trade Journal, 1927, vol. 36, Aug. 25, pp. 169-173). It is shown that on adding aluminium to a pure white iron containing no silicon a series of soft machinable grey irons is obtained between 1 and 8 per cent. of aluminium, this series being analogous in general properties and microstructure to the grey irons in the pure silicon-iron-carbon system, aluminium acting less powerfully than silicon as a softener, 2 to 3 per cent. of aluminium being required to produce an iron comparable with one containing 1 per cent. of silicon, while the maximum percentage of carbon graphitised is 61 per cent. at 4 per cent. aluminium, as against 70 per cent. at 3 per cent. silicon. This is in opposition to the results put forward by Melland and Waldron (Journ. I. and S.I., 1900, No. II. p. 244), but it must be remembered that silicon (0.24 per cent.) was present in the iron used in their research, and this, acting with the aluminium, would accentuate the influence of the latter on the carbon. Graphite occurs in a finer form in the aluminium than in the silicon series. Above 8 per cent. aluminium a hard, brittle range is found extending up to 18 per cent. In this range the carbon is all combined. Above 18 per cent. aluminium the alloys soften again, and graphite is precipitated, giving a second graphitic range from 18 to 25 per cent. aluminium. Above 25 per cent. aluminium the alloys become unstable in the atmosphere.

E. Piwowsky, *On the Effect of Nickel and Chromium on the Strength Properties of Grey Cast Iron* (Paper read before the Institute of British Foundrymen, July 1927 : Foundry Trade Journal, 1927, vol. 36, July 7, pp. 4-6 ; July 14, pp. 37-40 ; Die Giesserei, 1927, vol. 14, July 23, pp. 509-515). The author presents the results of tests made to determine the influence of nickel and chromium on the mechanical properties of high quality cast iron. By causing a cast iron to solidify at first mainly white by accelerated cooling, and graphitising it only by subsequent annealing so that it contained (1) the primary carbon in the finest and most favourable arrangement possible, and (2) as fine-grained a sorbitic-pearlite ground-mass as possible, mechanical strengths of a range hitherto unreached were obtained. In high-grade material of this kind, an improvement in properties of 10 to 30 per cent. was obtained by nickel and chromium additions. The deflection of such material in the transverse test is two or three times that of ordinary pearlitic grey cast iron. Tensile tests in which the elimination of defects in the test-piece was ensured showed measurable elongations of 2 to 4 per cent., with values up to 75 kg./mm.² (47.6 tons per sq. in.). Notwithstanding the high hardness figures (200 to 300), the machinability of all the samples was at least as good as that of ordinary

good quality grey cast iron. The author points out the practicability of producing a high quality malleable cast iron by quick annealing of white or mottled irons.

P. Oberhofer and E. Piwowarsky, *The Use of Nickel-Chromium Cast Iron, with Special Reference to Practice in the United States* (Die Giesserei, 1927, vol. 14, Aug. 27, pp. 585-592). An exhaustive research on the influence of nickel and chromium additions to cast iron.

R. S. Poister, *The Effects of Chromium and Nickel in Cast Iron* (Paper read before the American Foundrymen's Association, June 1927). The author summarises the results of early investigators, which appear definitely to establish that 0.50 per cent. of chromium in the presence of 1 to 2 per cent. of silicon increases the tensile and transverse strengths and hardness of cast iron. More recent work has generally verified the results of the earlier investigations, and it has also yielded data relating to improvements other than increased physical strength. The author points out that the field for a cheaper heat-resisting iron is almost unlimited, but the high-chromium cast irons are so hard and brittle that their commercial use is restricted. The brittleness can be reduced by lowering the carbon to about 2.50 per cent. Annealing will reduce the initial hardness, but has very little effect towards improving the transverse strength. Grey irons containing small amounts of chromium show pronounced resistance to oxidation at high temperatures. Also a small addition of chromium increases strength, while further additions increase the hardness at the expense of strength and deflection. The greatest benefit from the use of chromium may be expected through the adjustments between chromium and silicon content. By the addition of both nickel and chromium better physical properties can be imparted to a grey iron than are possible by either element alone. Nickel and chromium in proportions of three to one or two to one, depending on the silicon, afford an improvement in structure, strength, toughness, machinability, and resistance to abrasion. According to the author, the best method of making additions of ferrochromium to the cupola is in the form of briquettes, using cement or refractory clay as a binder.

J. H. Andrew, *The Growth of Cast Iron* (Paper read before the American Foundrymen's Association, June 1927). The paper opens with a brief summary of the work of previous investigators, which shows that, while a certain conformity of viewpoint does exist, the different workers are by no means unanimous in their opinions regarding the underlying causes of growth in cast iron. From the work of others and his own the author concludes that growth is brought about as follows: (1) By graphitisation of combined carbon. (2) By percolation of air through the graphite flakes and channels in the iron, bringing about oxidation of the ferrite, with formation of Fe_3O_4 and probably finely divided carbon. (3) A certain amount of contraction will eventually result from oxidation of the graphite and deposited carbon, but this may be balanced by further and continuous oxidation of the

ferrite. (4) Every time the iron is heated and cooled its structure will be changed due to the previous treatment, with the result that the coefficient of expansion will have altered. Further, the expansion of oxide material and direction in which this lies with respect to the length of the section employed will bring about a difference in total expansion at every heat, and will result in a breaking apart of the particles at certain areas, which in itself will cause growth. (5) The author does not think that occluded gases, or rather their physical effect, can bring about any permanent expansion. Oxidised gases in reacting with the iron or the carbon will, of course, have the same effect as similar gases added externally.

W. Schwinning and H. Flössner, *The Growth of Cast Iron* (Stahl und Eisen, 1927, vol. 47, June 30, pp. 1075-1079; abstract, Foundry Trade Journal, 1927, vol. 36, Sept. 22, 1927). The authors describe experiments on five kinds of commercial cast iron, the specimens being cast in bars 300 mm. long and 20 mm. diameter, and turned down to 160 mm. length and 15 mm. diameter. One bar was cast in a chill and solidified as white iron. The composition of the bars averaged: total carbon 3.50, silicon 2.60, manganese from 0.46 to 0.91, phosphorus from 0.12 to 0.83, and sulphur from 0.062 to 0.154 per cent. The experiments showed that the growth at temperatures of 550° to 650° is mainly due to the decomposition of the pearlitic cementite. Two types of dissociation were noted. At low temperatures a delayed dissociation occurs, which causes longitudinal growth to proceed in two stages.

J. G. Hurst, *Distortion and Growth in Cast Iron on Repeated Heating* (Chemical Age, 1927, vol. 16, June 4, pp. 41-42). The growth of cast iron under repeated conditions of heating and cooling is discussed, and compared with the spalling phenomenon exhibited by refractory materials.

K. Sipp and F. Roll, *The Growth of Cast Iron* (Giesserei Zeitung, 1927, vol. 24, May 1, pp. 229-244; May 15, pp. 280-284; abstract, Foundry Trade Journal, 1927, vol. 36, Aug. 4, pp. 114-116).

E. Morgan, *Thermal Expansion of Cast Iron* (Bulletin of the British Cast Iron Research Association, July 1927, No. 17, pp. 6-7).

S. N. Petrenko, *Comparative Tests of 6-in. Cast-Iron Pipes of American and French Manufacture* (United States Bureau of Standards, 1927, Technologic Paper No. 336). Comparative tests were made on cast-iron pipe manufactured in France and on similar pipe manufactured in America. The pipes were of the "bell and spigot" type and were cast in sand moulds. The tests, which included hardness, transverse, ring, shear, impact, and hydrostatic tests, showed that the strength of the French pipe lay within the range of variation of the American pipe. Its deflection in transverse test was much lower than that of American pipe. The French pipe was also characterised by greater hardness, low impact values, and a higher content of phosphorus (about 1.85 per cent.) than the American pipe. The compressive test of the rings cut

from the pipe seemed to give results which are fairly representative of the properties of the pipe, and the test is suggested as a substitute for the transverse test of arbitration bars or coupons.

M. E. Greenhow, *Tensile and Transverse Strength of High Strength Cast Iron* (Paper read before the American Society for Testing Materials, June 1927). The author discusses cupola practice, iron mixtures, temperatures, the influence of temperature on strength, ladle alloying, comparative hardness and machinability of plain and alloy irons.

E. Decherf, *Hypoeutectic Cast Irons for Rolling-Mill Guides (Wire Mills)* (Revue Universelle des Mines, 1927, vol. 14, June 15, pp. 243-247). The microstructures and analyses of four cast irons, which were used to make experimental guides for the last stand of a wire mill, are described and discussed. Observations are made on the guides which in actual use show which metal gave the best results in practice.

Cast-Iron Pipe Flanges and Flanged Fittings (Mechanical Engineering, 1927, vol. 49, Aug., pp. 926-928). *Malleable and Cast-Iron Screwed Fittings* (Mechanical Engineering, 1927, vol. 49, Sept., pp. 1028, 1038). Tentative American Standards have been drawn up by a Sectional Committee on the Standardisation of Pipe Flanges and Fittings, the sponsor organisations of which are the Heating and Piping Contractors National Association, the Manufacturers' Standardisation Society of Valve and Fittings Industry, and the American Society of Mechanical Engineers. The malleable iron screwed fittings are designed for 150 lb. per sq. in. pressure, and the cast-iron standards are for 125 lb. and 250 lb. per sq. in.

H. Matsuura, *Castings for Diesel Engines* (Foundry Trade Journal, 1927, vol. 36, Aug. 25, pp. 175-177). The author has investigated the tensile properties at high temperature and the wearing qualities of cast iron, and outlines the requirements for cast iron for Diesel engines. Tests were also carried out on a number of 25 per cent. semi-steel samples containing from 0.66 to about 4 per cent. manganese. The results show that the increasing manganese content in semi-steel containing about 3.0 per cent. total carbon and 1.6 per cent. silicon arrests in a marked degree the rate of loss of strength and hardness, as well as the rate of growth when subjected to repeated heating and cooling. The best results were obtained in the semi-steel containing 2.54 per cent. of manganese. The strengthening effect of manganese upon the cast iron seems to be due to the fact that the form of pearlite changes to sorbitic, and the retarding effect of the manganese upon the decomposition of pearlite carbide at high temperature may be due to the greater stability of double carbide $(\text{FeMn})_3\text{C}$ at high temperature compared with single carbide Fe_3C . The heat of formation of $(\text{FeMn})_3\text{C}$ is probably greater than that of Fe_3C , because Mn_3C evolves 10,400 cals., while Fe_3C evolves 8460 cals.

F. B. Coyle, *Properties and Heat Treatment of Cast Iron for Diesel Engines* (Transactions of the American Society for Steel Treating 1927, vol. 12, Sept., pp. 446-465). The author discusses the properties

of cast iron and the effect of heat treatment on the Brinell hardness and tensile strength.

Properties and Tests of Steels.—B. Kjerrman, *Determining the Proportional Limit of Steel* (Transactions of the American Society for Steel Treating, 1927, vol. 12, July, pp. 41–45). The author describes a new arrangement of holding tension test-pieces, which is particularly useful when determining the proportional limit. It not only gives more correct results, but it makes the whole test more convenient to perform, because of the very uniform movement of the mirrors. In order to obtain the correct proportional limit from load-deflection data the author proposes the method of calculating the elongation of the specimen corresponding to one load increment of about 1 or 2 kg. per sq. mm. (1422 to 2844 lb. per sq. in.), assuming for steel a modulus of elasticity of 28,400,000. The proportional limit, if not clearly detected otherwise, may be considered reached as soon as the observed increments of elongation exceed the calculated.

In a test the limit thus found was the same, whether the load had been increased in many or in few steps, the final load increments in both cases being the same.

G. Welter, *Material Testing from the Standpoint of Manufacture and Use* (Zeitschrift für Metallkunde, 1927, vol. 19, June, pp. 232–237; July, pp. 265–272). The constants of materials, which come into play during the production and use of structural parts, are subjected to a close examination. As regards the behaviour of the material during manufacture, besides the crystalline structure, resistance to change of shape and ability to change shape at various temperatures, which may be determined by the usual testing methods, are of first-rank importance. In the application of the material in construction, on the contrary, totally different requirements have to be met, which are, in particular, of an elastic nature. Reference is made to the insufficiency of the ordinary tests as criteria of the behaviour of the material when in use, and arguments, based on comprehensive test results on elastic and microplastic deformation, against the value of elasticity measurements are put forward. The causes of the faulty results often obtained in measuring the elasticity are discussed, and new testing apparatus for the determination of the elastic and micro-plastic properties are described.

J. E. Howard, *On the Properties of Steels* (Transactions of the American Society for Steel Treating, 1927, vol. 12, Oct., pp. 622–629, 650). The author discusses the various physical properties of steel and their behaviour under different conditions. Some of the points discussed are Poisson's ratio, Hooke's law, elastic limit, elongation and contraction of area, modulus of elasticity, and coefficients of expansion. The influence of some of these properties on steel rails is discussed.

A. L. Kimball and D. E. Lovell, *Internal Friction in Solids* (Paper read before the American Society of Mechanical Engineers, Dec. 6–9, 1926:

abstract, Mechanical Engineering, 1927, vol. 49, May, pp. 440-442). In connection with a test devised to determine quantitatively the amount of friction within the metal of a steel shaft involved in dissipating vibration, and also in producing shaft whipping, it was found that the internal frictional forces were quite unlike those of a viscous fluid, where the forces are greater the more rapid the deformation; the dissipative forces were found to be the same, whatever the speed of deformation. The apparatus with which the tests were conducted is described, and the results are tabulated. Equations relating the variables involved are derived in the analysis of the problem.

F. Sauerwald and H. Viessen, *Mechanical Properties of Hardened and Annealed Carbon Steels* (Centralblatt der Hütten- u. Walzwerke, 1927, vol. 31, Apr. 27, pp. 207-211). The results of tests on pearlitic steel and tool steel show that the elastic strength varies directly and hardness inversely with the temperature and duration of annealing.

F. Körber, *The Problem of the Elastic Limit* (Paper read before the International Testing Congress, Amsterdam, 1927).

G. Welter, *Elasticity of Metals and Alloys* (Paper read before the International Testing Congress, Amsterdam, 1927).

E. G. Coker, *Photo-Elastic Measurements of Stress Distribution* (Journal of the Royal Society of Arts, 1927, vol. 75, Sept. 9, pp. 1017-1028; Sept. 16, pp. 1033-1055; Sept. 23, pp. 1060-1079). The author discusses the fundamental principles of photo-elasticity and their application to the measurement of stress, describes an apparatus for obtaining a beam of plane polarised or circularly polarised light and instruments for measuring loads and stresses, and details the stress distribution results obtained on a large variety of objects of all sorts of shapes, under various methods of loading.

E. Marcotte, *Mechanical Applications of the Phenomenon of Double Refraction* (Arts et Métiers, 1927, vol. 80, Apr., pp. 117-127; May, pp. 170-179). The phenomenon of double refraction is minutely explained, and its application to the testing of stress distribution in machine parts by means of transparent models is described.

G. Delanghe, *Photo-Elasticimetry* (Génie Civil, 1927, vol. 91, Sept. 10, pp. 243-249; Sept. 17, pp. 271-275; Sept. 24, pp. 297-304). The application of photo-elasticity to the evaluation of stresses in structural and machine parts is discussed. The La Balme Bridge over the Rhône and gear teeth, links, &c., are taken as examples.

S. Sekito, *X-Ray Investigation of the Internal Stress in Metals* (Science Reports of the Tôhoku Imperial University, Sendai, 1927, vol. 16, pp. 343-355).

J. H. Smith, *Rate of Elongation in Tension Tests* (Paper read before the American Society for Testing Materials, June 1927). The author presents the results of tests obtained with the use of a new autographic stress-strain instrument, with time-recording mechanism attached. The tests were planned to show the variation of rates, throughout the critical stages, for various sizes and shapes of specimens and various

methods of gripping. The materials tested included hot-rolled, cold-rolled, and cold-drawn steels. Diagrams and tables show the ratios between movement of the head of the testing machine, slipping of grips, slipping of specimen, and its rate of elongation.

J. T. Nichols, E. S. Taylerson, and J. C. Whetzel, *Tension Test Specimens for Sheet Steel* (Paper read before the American Society for Testing Materials, June 1927). An extensive series of tension tests were carried out on sheet steel of various grades and thicknesses, using seven different test specimens, and also varying the radius of fillet and the end width. The results show that while the yield point and tensile strength are only slightly affected by the shape of the specimen, the percentage of elongation varies appreciably with gauge length and cross-sectional area. This relation for sheet steel is in agreement with the work of previous investigators on other metals. The precision of the results for different designs of test specimen indicates that a gauge section 2 in. long and $\frac{1}{2}$ in. wide is suitable for testing sheet steel.

R. L. Templin, *Methods for Determining the Tensile Properties of Thin Sheet Metals* (Paper read before the American Society for Testing Materials, June 1927). The author describes methods for determining the tensile properties of thin sheet metals varying in thickness from 0.005 to 0.250 in. Economical methods for the machining of tension test specimens, application of gauge marks, and the measuring of specimen dimensions are discussed. Proper methods for gripping specimens, types of testing machines, testing speeds, and a method for determining "yield point" are described in detail.

Observations on Testing of Sheet Steel (Blast-Furnace and Steel Plant, 1927, vol. 15, Nov., pp. 528-531). A comparison of the testing methods used, and an account of the internal defects found, in the deep and extra deep drawing of sheet steel. Segregation, inclusions, &c., are also considered.

J. Winlock and G. L. Keeley, *Testing Automobile Body Sheet Steel* (Transactions of the American Society for Steel Treating, 1927, vol. 12, Oct., pp. 635-650). Sheet steel used in automobile bodies must meet severe requirements as to surface and ductility. The authors discuss briefly the conditions governing the making of stampings, and present the results obtained in tests in which the physical properties of the steel are shown in their relation to its performance on the die.

Ch. Frémont, *Superficial Deformations and the Distribution of Forces* (Génie Civil, 1927, vol. 91, July 2, pp. 10-13). The author discusses the formation of Lüder's lines and their application to the investigation of the distribution of stresses in tensile test-pieces.

New Testing Method for High Tensile Steel Wires (Génie Civil, 1927, vol. 90, Jan. 8, pp. 41-45). A review of recent work by Frémont, in which his apparatus and test results and micrographs are reproduced.

Ch. Frémont, *The Cause of the Formation of the Cup in the Fracture of Test-Pieces in Tension* (Génie Civil, 1927, vol. 90, May 7, pp. 453-456).

G. Sachs, *The Detection of Internal Stresses in Rods and Tubes* (Zeitschrift für Metallkunde, 1927, vol. 19, Sept., pp. 352-357). The author develops a method for the complete determination of the internal stresses in rods and tubes. Measurements on tube sections show that in the outer skin especially high circumferential tensile stresses are to be found. The method consists in removing successive layers from the inside of the tubes and measuring the resulting changes in length and thickness; solid cylinders are treated in the same manner. The mathematics required for the evaluation of the results obtained are fully dealt with.

J. Seigle, *Conditions for the Apparition of Strain Lines Marking the Commencement of Permanent Deformations* (Génie Civil, 1927, vol. 90, June 11, pp. 576-578). Test-pieces of various shapes and in various conditions (with or without notches, hammered in parts, heat-treated, &c.) were submitted to tension, torsion, bending, and other tests to investigate the apparition of strain lines.

W. Kuntze and G. Sachs, *The Tensile Test on Flat Bars* (Stahl und Eisen, 1927, vol. 47, Feb. 10, pp. 219-226; abstracts, Metallurgist, 1927, Apr. 29, pp. 61-63; Journ. I. and S.I., 1927, No. 1. p. 924).

W. Rosenhain, *The Plastic Deformation and Fracture of Metals* (Paper read before the International Testing Congress, Amsterdam, 1927: abstract, Engineer, 1927, vol. 144, Oct. 14, pp. 422-423). A summary of the position of the various problems relating to the plastic strain and fracture of metals as they stand to-day.

A. Lundgren, *The Testing of Hardened Steel* (Paper read before the International Testing Congress, Amsterdam, 1927).

M. Lorenz, *Compression Experiments with Unreheated Cast Steel at Higher Temperatures* (Dissertation to the Bergakademie zu Freiberg, Nov. 1925). The experiments recorded were carried out to determine the work absorbed in the hot-pressing at various temperatures of cast steel of various compositions and the influence of the mechanical working of the metal on the Widmannstätten structure, particularly to discover what degree of working was necessary to convert the elongated structure to the granular form.

W. F. Schaphorst, *Collapsing Strength of Thin Tubes and Pipes in Chemical Plants* (Industrial and Engineering Chemistry, 1927, vol. 19, Aug., p. 887). The author suggests a method of computing the collapsing strength of tubes and pipes.

R. T. Rolfe, *The Testing of Materials* (Iron and Steel Industry, 1927, vol. 1, Oct., pp. 15-17). The author, while he does not minimise the value of chemical and microscopical examination of failures, emphasises that "large-scale" investigations by means of macro-etchings, examination of fractures, &c., should not be neglected, as they may often reveal information not obtainable by the other means.

Report of Committee E1 on Methods of Testing (American Society for Testing Materials, June 1927). The requirements for a standard tension test specimen for the testing of thin sheet metals are presented.

W. Rosenhain and D. Hanson, *The Behaviour of Mild Steel Under Prolonged Stress at 300° C.* (Paper read before the Iron and Steel Institute, Sept. 1927 : this Journal, p. 117).

J. Cournot, K. Sasagawa, and R. de Oliveira, *On some Experiments on Tensile Shock at Rising Temperatures* (Revue de Métallurgie, Mémoires, 1927, vol. 24, Apr., pp. 210-214). The Charpy pendulum testing machine was adapted to the tests. The test-bar, resembling the usual cylindrical tensile test-piece, was screwed by one end into the "back" of the pendulum bob; the other end was fastened to a cross-piece, which, when the pendulum was released, struck a pair of stops just at the moment when the centre of gravity of the moving mass was passing through the lowest point of its trajectory. Fastened to the cross-piece was the electric resistance furnace which encircled the specimen, its open end towards the bob being plugged loosely with insulating material; the feature of the arrangement is, of course, that the fracture of the test-piece actually took place within the furnace, which was disconnected from the heating current only at the moment when the experiment was ready to be performed. Straight carbon steels and nickel-chrome steels were investigated, and the results are contained in the paper. The dimensions of the straight carbon steel specimens were 180 mm. overall length, with a middle portion 50 mm. long and 6.4 mm. in diam.; the nickel-chrome test-pieces were of the same overall length, but the centre portion measured only 40 mm. long and 5 mm. in diam.

P. Henry, *Experimental Researches on the Speeds of Deformation of Metals at High Temperatures* (Revue de Métallurgie, Mémoires, 1927, vol. 24, Aug., pp. 421-442). The test-bar was deformed by applying a torsional couple to one end of it, while the other end was firmly held; the movement of the twisted end was observed by means of a beam of light reflected from a mirror attached to it. The test-bar was maintained at the required temperature in an electric furnace, a slow current of dry CO_2 preventing undue oxidation. A definite relation was found between the speed of torsion, the applied couple, and the temperature; in the case of iron and steel the limits of this relationship were about 400° and 800° C. The extension of this formula to cover tensile elongation is possible. A formula was also found to express the breaking load as a function of the temperature. Mechanically heterogeneous zones were found in steels at 850° and 450° C., and the crystallisation of ferrite in large grains at about 620° C. under a moderate mechanical stress was shown. The experiments also demonstrated the existence of viscous flow from the commencement of loading during the elastic range; the relationship between the load and the deformation is exponential both for torsion and tension.

A. Michel and M. Matte, *Variation of the Mechanical Properties of Steels and Alloys with the Temperature* (Revue de Métallurgie, Mémoires, 1927, vol. 24, Apr., pp. 200-209 : abstract, Metallurgist, 1927, Sept. 30, pp. 133-135). A review of the results obtained by various authors in

their researches into the variations of the tensile properties of steels and alloys at temperatures above the normal.

E. Houdremont and H. Kallen, *The Capacity for Deformation of Various Alloy Steels When Hot* (Stahl und Eisen, 1927, vol. 47, May 19, pp. 826-830). Static and dynamic tests were made to determine the resistance of chromium, chromium-nickel, tungsten, and high-speed steels to deformation in the hot state. The resistances per sq. mm. in kilogrammes and the speed of deformation in cu. mm./cu. mm. \times sec., are tabulated for temperatures from 650° to 1100°.

H. J. Tapsell and W. J. Clenshaw, *Properties of Materials at High Temperatures* (Department of Scientific and Industrial Research, Engineering Research, Special Reports, Nos. 1 and 2, 1927). The first report deals with the mechanical properties of Armco iron, 0.17 per cent. carbon steel and 0.24 per cent. carbon steel, with special references to creep; the second report is concerned with the same properties of 0.51 per cent. carbon steel, and 0.53 per cent. carbon cast steel. The tests carried out were: tensile tests, including modulus determinations, at various temperatures; creep tests and determinations of the effect of maintaining loads over extended periods at high temperatures; torsion tests, including modulus determinations, at various temperatures; impact tests (notched bar); hardness tests (Brinell and impact), and fatigue tests. The results are set out in tables and graphs, and those recorded in the first report are discussed.

G. C. Priester and O. E. Harder, *Effect of Temperature on the Mechanical and Microscopic Properties of Steel* (Transactions of the American Society for Steel Treating, 1927, vol. 12, Sept., pp. 436-445). The authors describe the results of tests on a quenched 0.29 carbon steel at temperatures up to 1112° F. (600° C.), and on the same steel as hardened, tempered at temperatures up to 1112° F., and then tested at room temperature. Only tensile tests were made at elevated temperatures, while the tests at room temperature also included hardness and impact toughness. A falling off in the ultimate strength and proportional limit of the quenched steel was found in the region of about 212° F. and a maximum at about 572° F. The reduction of area showed a marked increase at 572° F. In the case of the quenched and tempered specimens, the Shore hardness curve seems to resemble the ultimate strength curve, while the Brinell hardness curve is more like the proportional limit curve.

G. Urbanczyk, *Mechanical Properties of Boiler Plate at Temperatures from 20° to 600°* (Stahl und Eisen, 1927, vol. 27, July 7, pp. 1128-1135). Results of tensile and notched-bar tests are given on the four new kinds of boiler plate made to the Oct. 1926 specifications for land boilers. The types of material called for have the following tensile limits: (1) 22.2-28.0 tons/sq. in.; (2) 26.1-31.8 tons/sq. in.; (3) 28.0-33.7 tons/sq. in.; (4) 29.9-35.6 tons/sq. in. 144 tensile and 144 notched-bar test-bars were taken from each plate, half longitudinally and half transversely. It appears that the yield point

alters very little up to 200° and then falls with rising temperature, whilst the tensile rises with the temperature up to 275° and then falls rapidly. The elongation behaves in the opposite manner, *i.e.* a fall to about 250° followed by a rise. The reduction in area shows a minimum between 200° and 250° , and then rises with increasing temperature. The notched-bar results show at first a rise with a maximum at 120° , after which they fall to a minimum between 500° and 600° . Between 200° and 350° all four materials show a figure ≥ 14 kgm./sq. cm. A table of minimum figures for yield and break at various temperatures is given as data for the design of boilers constructed from these four materials.

A. E. White and C. L. Clark, *Properties of Boiler Tubing at Elevated Temperatures Determined by Expansion Tests* (Paper read before the American Society of Mechanical Engineers, Dec. 6-9, 1926 : Mechanical Engineering, 1927, vol. 49, Oct., pp. 1093-1097). The object of the investigation was to determine safe working loads for low-carbon steel seamless tubing at elevated temperatures. Present-day boiler practice employs temperatures ranging from 550° to 750° F., and pressures of about 350 lb. per sq. in. There is a tendency to increase both temperature and pressure, but little is known of the properties of metals at high temperatures, especially when the temperatures are maintained for long periods. The preliminary findings on 0.13 per cent. carbon steel tubing when loaded at temperatures of 900° , 1000° , 1250° , and 1500° F. are recorded.

A. E. White, *Tests and Properties of Metals at High Temperatures* (Paper read before the International Testing Congress, Amsterdam, 1927).

Rabozée, *Influence of Heat and Mechanical Treatment upon the Resistance of Materials to Repeated Stresses* (Paper read before the International Testing Congress, Amsterdam, 1927).

A. Hultgren, *The Fatigue Properties, Impact Resistance, and Hardness of Some Nickel-Chromium Gear Steels, Case-Hardened, Oil-Hardened, and Air-Hardened Respectively* (Ingeniörsvetenskapsakademien, Handlingar, Nr. 59, 1927, 55 pp.). The author discusses what properties are desirable in materials for use in the manufacture of gears of the automobile type, and the choice of suitable steels, and their appropriate heat treatments, for that purpose; in particular, the usual mechanism of failure is inferred from observations made on gears which have failed, the nature and distribution of stresses in gear teeth, and the danger of cracking and amount of distortion in heat-treating are dealt with. The results of fatigue (rotating bending), impact and hardness tests carried out on some nickel-chromium steels to determine their suitability for use in gears, are described. The author concludes that, for gears or other objects subjected to numerous repeated or alternating stresses without severe shocks, the case-hardened steels tested were superior. The oil-hardened steels were next in order of merit, and showed better results when polished after heat treatment,

a feature not apparent in the well case-hardened specimens. Under the conditions of the tests the air-hardened steel was inferior to all the other steels tested.

H. J. Gough, *Some Modern Views on the Fatigue of Metals* (Paper read before the Institution of Structural Engineers, Feb. 10, 1927 : Engineer, 1927, vol. 143, Apr. 29, pp. 474-477). The author reviews some of the modern theories of the fatigue of metals, and deals in more detail with the theory of strain-hardening governing the behaviour of metals under static and repeated stresses, evolved by himself and Hanson.

H. F. Moore, *A Study of Fatigue Cracks in Car Axles* (Illinois University, Engineering Experiment Station, Bulletin No. 165). The tests reported in this bulletin are believed to give some significant information concerning the appearance and spread of fatigue cracks caused by repeated stress in car axles. The tests do not cover sufficient ground to give any precise quantitative values for limiting stresses or rates of spread of cracks. With the use of a rotating-beam type of testing machine, fatigue cracks were produced in specimens cut from car axles. The critical diameter of these specimens was about 1 in., and under various conditions of stress a study was made of the progress of fatigue cracks from their first appearance to the complete fracture of a specimen. Fatigue cracks were detected by the use of a low-power microscope, and also by the discoloration of a coating of whiting on the specimen by oil squeezed out of a crack when the specimen was subjected to bending stress. The oil and whiting method is one used in shop practice. The following summary of conclusions is given: (1) By means of simple methods, such as are used in some railroad shops, fatigue cracks in test specimens cut from car axles and subjected to repeated stress were detected before final failure of the specimen occurred. (2) Specimens in which a fatigue crack was produced by cycles of stress 20 per cent. above the fatigue limit resisted before final fracture from 250,000 to 1,000,000 cycles of stress after the crack had been detected. (3) The higher the stress the fewer were the cycles of stress occurring between the detection of a fatigue crack and the failure of the specimen, and the larger the percentage of the elapsed "life" of the specimen at the appearance of the crack. (4) For test specimens having a diameter of 0.3 in. for a given stress fewer cycles of stress occurred between detection of a crack and final failure than was the case for specimens having a diameter of 1 in. It seems reasonable to conclude that for car axles having a diameter of 4 to 6 in. the number of cycles of stress between the appearance of a detectable crack and failure would be materially larger than was the case for the 1 in. specimens. (5) Test specimens in which a fatigue crack had been started and had spread to a definite length showed a continuing spread of such a crack to failure under subsequent cycles of stress having a magnitude of 64 per cent. of the endurance limit of the virgin steel ; but such a crack in a test specimen did not spread further under cycles

of stress having a magnitude of 50 per cent. of the endurance limit of the virgin steel. (6) The results of these tests, taken in conjunction with service records, seem to indicate that periodical shop inspection by means of the oil-whiting test described may be expected to have a good degree of effectiveness in detecting incipient fatigue cracks in car axles in service, before failure of the axle is imminent.

H. F. Moore, *The Fatigue of Metals* (Paper read before the International Testing Congress, Amsterdam, 1927).

D. J. McAdam, jun., *Fatigue and Corrosion Fatigue of Metals* (Paper read before the International Testing Congress, Amsterdam, 1927).

O. Föppl, *Behaviour of Structural Steel under Repeated Torsional Stress* (Zeitschrift des Vereines Deutscher Ingenieure, 1926, vol. 70, Sept. 25, pp. 1291-1296).

T. H. Burnham, *Torsional Fatigue Limits* (Engineering, 1927, vol. 124, July 8, pp. 33-34). An illustrated abstract in English of the above paper by Föppl.

Determination of the Fatigue Hardness of Metals (Engineering Progress, 1927, vol. 8, May, pp. 131-132). An oscillatory testing machine is described for the testing of bar-shaped test-pieces under tension and compression alternating at 500 oscillations per second.

J. K. Wood, *Hysteresis Relative to the Operation of Mechanical Springs* (Paper read before the American Society of Mechanical Engineers, May 23-26, 1927 : Mechanical Engineering, 1927, vol. 49, Mid-May, pp. 561-569). Mechanically, hysteresis, or the lag of observed effects behind their causes, has not been considered as extensively as in electrical design. Springs, and spring systems in particular, are shown by the author to be associated with three characteristic types of physical hysteresis—namely, mechanical, hypo-elastic, and hyper-elastic. Mechanical hysteresis is caused by external agencies, while both hypo- and hyper-elastic hysteresis are caused by the internal behaviour of crystalline structures. Hypo-elastic hysteresis is due to an internal friction of the solid type, presumably at the grain boundaries, and hyper-elastic hysteresis is due to slip or plastic flow and, hence, has a characteristic time factor. The concept of hypo- and hyper-elastic energies with their corresponding hysteresis effects enables a better understanding of certain physical properties of metals, particularly those important to mechanical springs. Although elastic-hysteresis effects are of a much lower order than those due to mechanical hysteresis, they are sufficiently large to be given serious consideration in the design of measuring devices.

L. Jannin, *Study of the Phenomena of Elastic Hysteresis in Some Alloys* (Revue de Métallurgie, Mémoires, 1926, vol. 23, Dec., pp. 709-717 ; abstracts, Metallurgist, 1927, July 29, pp. 105-107 ; Journ. I. and S.I., 1927, No. I. p. 924).

N. P. Inglis, *Hysteresis in Metals Under Alternating Stresses* (Metallurgist, 1927, Sept. 30, pp. 138-140).

R. Guillery, *Telescopic Dynamometers* (Revue de Métallurgie, Mémoires, 1927, vol. 24, July, pp. 401-404). The author describes a new type of dynamometer in which the load is balanced by elastic forces of a purely compressional or extensional character. This end is attained by the use of "springs" consisting of concentric cylinders of constant section, working alternately in compression and extension; the elasticity is that of the cylinder metal itself. The instrument, which is light, strong, and reasonably accurate, is considered to be an advance on the so-called piezometric rings.

O. S. Peters, *Recent Developments and Applications of the Electric Telemeter* (Paper read before the American Society for Testing Materials, June 1927). The author describes the further development and practical applications of the electric telemeter. This instrument measures strains set up in a structure and records them at a distance with sufficient accuracy for engineering purposes.

Memmler, *Testing and Calibration of Testing Machines* (Paper read before the International Testing Congress, Amsterdam, 1927).

R. K. Barry, *Comparisons of Impact and Slow-Bend Tests of High-Speed Steel* (Transactions of the American Society for Steel Treating, 1927, vol. 12, Oct., pp. 630-634). In a previous paper (Transactions of the American Society for Steel Treating, 1926, vol. 10, Aug., pp. 257-259) the author gave the results of tests carried out to determine the influence of various tempering temperatures on the hardness and toughness of high-speed steel. The present paper gives the results of additional tests carried out by two other investigators in collaboration with the author. The results obtained show that high-speed steel is harder after tempering at 1100° F. than when tempered at 900° F.; it will therefore have a higher tensile strength and higher transverse breaking strength with maximum deflection, which would tend to increase the brittleness and to decrease the deflection under slow bend. High-speed steel tempered at 900° F. is tougher or more ductile than when tempered at 1100° F., which was indicated by impact test.

A. B. Kinzel, *A Critical Study of the Bend Test as Applied to Iron and Steel* (Transactions of the American Society for Steel Treating, 1927, vol. 12, Nov., pp. 778-793, 826). The paper includes a theoretical study of the strains produced on bending a rectangular bar. From this theory there is deduced a method for the quantitative evaluation of a bend test. The phenomena of cracking on the inside surface of the bar, and the relation between tensile and bend elongation, are discussed. Specifications for routine quantitative bend testing are given.

H. Hanemann and R. Hinzmann, *The Influence of Grain-Size on the Mechanical Properties of Steels, with Special Reference to the Notched-Bar Test* (Stahl und Eisen, 1927, vol. 47, Oct. 6, pp. 1651-1661). The influence of grain-size on certain properties of a carbon steel and a treated nickel-chrome steel was investigated. The effect of grain-size between 600 and 13,000 μ^2 in the case of the carbon steel, and between 90 and 25,000 μ^2 in the nickel-chrome steel, was too slight to

be observable. The "specific notch toughness" does not correspond with the evaluation of the real results of the test. The "deformed volume" and "speed of blow" must be taken note of by tests on two pieces, by which means two material properties, the "mean work per unit (deformed) volume" and the "speed of working," are determined. In testing the influence of the grain-size on these two material properties a "dangerous grain-size," which should not be exceeded, was established. The term "work per grain" was introduced and discussed.

K. Honda, *Theoretical Considerations on Static and Dynamic Tensile and Notched-Bar Tests* (Science Reports of the Tôhoku Imperial University, Sendai, 1927, vol. 16, pp. 265-277). It is pointed out that the energy required for the actual breaking of a test-piece is mainly used up in the deformation of the test-piece. The difference in the energy expended for the breaking of a test-piece in the static and dynamic tension test, and also the equality of energy in the static and dynamic bending tests, are explained. In the case of repeated impact tests a method for studying the degree of fatigue in a test-piece, which progresses during repeated impacts preceding its breaking, is proposed.

H. Sieglerschmidt, *Bending Capacity of Wire Ropes* (Zeitschrift des Vereines Deutscher Ingenieure, 1927, vol. 71, Apr. 16, pp. 517-520). Rolling bend tests and alternating bend tests show that the changes in the bending number follow a similar law, and the tests may be regarded as similar in principle, but in general the alternating test gives no indication of the bending capacity in bending over rollers of large diameter. No definite connection between bending capacity and the tensile properties could be established.

Schimming, *Impact Testing on Ordinary and Notched-Bars* (Paper read before the International Testing Congress, Amsterdam, 1927).

P. Régnault, *The Brittleness of Steel* (Revue de Métallurgie, Mémoires, 1927, vol. 24, Sept., pp. 509-515).

J. H. Smith and F. V. Warnock, *A Testing Machine for Repeated Impact, and a Preliminary Investigation on the Effects of Repeated Impact on Lowmoor Iron* (Paper read before the Iron and Steel Institute, Sept. 1927: this Journal, p. 323).

F. C. Lea and F. Heywood, *The Failure of Some Steel Wires Under Repeated Torsional Stresses at Various Mean Stresses Determined from Experiments on Helical Springs* (Paper read before the Institution of Mechanical Engineers, Apr. 29, 1927: Engineering, 1927, vol. 123, May 6, pp. 562-564; May 20, pp. 621-623).

W. Bader and A. Nadai, *Behaviour of Torsion Test-Bars in which the Limit of Flow has been Exceeded* (Zeitschrift des Vereines Deutscher Ingenieure, 1927, vol. 71, Mar. 8, pp. 317-323). Deals with the deformation and flow of material in round iron bars subjected to stresses exceeding the limit of flow.

B. Garre, *On Changes in the Solubility and Hardness of Metallic Materials Caused by Twisting and Bending* (Zeitschrift für anorganische

Chemie, 1927, vol. 161, pp. 305-308; Korrosion und Metallschutz, 1927, vol. 3, Jan., pp. 1-5): abstract, *The Effect of Torsion and Bending on Soft Steel* (Metallurgist, 1927, July 29, pp. 107-109). See Journ. I. and S.I., 1927, No. I. p. 929. The rate at which iron dissolves in dilute sulphuric acid increases directly with the number of twists to which the metal has been subjected in a torsion testing machine, while, on the other hand, the diameter of the impression of a standard Brinell ball under a pressure of 3000 kg. decreases logarithmically under the same conditions. The solubility of iron is also found to be greater after bending than before.

G. Keockgyarto, *Torsion Tests* (Paper read before the International Testing Congress, Amsterdam, 1927).

Ch. Frémont, *Contribution to the Study of the Undulatory Wear of Rails* (Génie Civil, 1927, vol. 91, Oct. 1, pp. 327-329). Thin slips of paper were placed on the rail and one wheel of a tramway car was allowed to roll across it at various speeds, the rail being in various conditions of wear. The "filigree" effect of the paper after the experiment was used to investigate the undulatory wear of the rail, and it was confirmed that the corrugations were due to vibrations of the rail. The rigid fixing of tram rails in the roadway was found to be an additional cause. It is suggested that the steel most likely to offer the best resistance to this form of wear is one with the highest elastic limit.

H. J. French, *Wear Testing of Metals* (Paper read before the American Society for Testing Materials, June 1927). The author discusses the factors affecting the wear of metals and some of the difficulties encountered in making both laboratory and service wear tests. Two testing machines are briefly described. The paper is a brief summary of the present status of wear testing of metals, and includes results of experimental work to show that reproducible results and information consistent with practical experience can be secured in the laboratory.

W. J. Merten, *Wear Resistance of Cutting Edges of Blanking Dies and Shear Blades* (Transactions of the American Society for Steel Treating, 1927, vol. 12, Aug., pp. 195-207). The author has studied the effect of shearing and blanking of scale-coated sheets and plates upon the cutting edge of shear blade and die parts.

M. Spindel, *Wear Testing of Materials* (Paper read before the International Testing Congress, Amsterdam, 1927).

R. Mailänder, *The Determination of Ball-Hardness of Thin Plates* (Kruppsche Monatshefte, 1927, vol. 8, Aug.-Sept., pp. 129-132). Tests to determine the ball pressure hardness of very thin plates will give accurate results if the supporting material on which the sheet is laid is of equal hardness, or if several thicknesses of the sheet, whose hardness is to be measured, are superimposed. The thickness which a sheet or several layers of the sheet to be tested should have, in relation to the hardness of the material, is represented by a curve.

G. W. Quick and L. Jordan, *Iron-Carbon-Vanadium for Brinell Balls* (Transactions of the American Society for Steel Treating, 1927, vol. 12, July, pp. 3-26, 50). The authors have carried out tests in which iron-carbon-vanadium alloy balls were used in the testing of very hard steel. These balls, heat-treated and work-hardened, proved more resistant to permanent deformation than Hultgren balls. The difference in flattening between the alloy steel balls and the Hultgren balls does not, however, appreciably affect the hardness number of steels up to 700 Brinell. The opinion that the hardness obtainable in a plain carbon steel by combined heat treatment and cold-work is the maximum hardness to be secured by such treatments, irrespective of the composition of the steel, is shown to be incorrect.

T. Ishigaki, *On the Effect of Grain-Size upon the Hardness of Iron* (Science Reports of the Tôhoku Imperial University, Sendai, 1927, vol. 16, pp. 285-293). The author has investigated the relationship between grain-size and hardness of iron. The mean increase of hardness of Armco iron per 1000 grain numbers was found to be 23 per cent., and that of the initial hardness for the same iron to be 51 per cent.

K. Honda and K. Takahasi, *On the Indentation Hardness of Metals* (Science Reports of the Tôhoku Imperial University, Sendai, 1927, vol. 16, pp. 357-382). See Journ. I. and S.I., 1927, No. I. p. 717.

G. Sachs, *Theory of Hardness* (Zeitschrift für technische Physik, 1927, No. 4, pp. 132-141).

R. Esnault-Pelterie, *New Method and New Apparatus for the Measurement of Hertzian Hardness* (Revue de Métallurgie, Mémoires, 1927, vol. 24, July, pp. 396-400). In a former communication (see Journ. I. and S.I., 1927, No. I. p. 931) the author described a method of measuring Hertzian hardness. In that method it was necessary to measure accurately the diameter of the circle of contact between two steel balls pressed against each other—a slow and tiring process. In the present paper the author describes a new electric resistance method of determining this same value, and reports that the new and more precise method has in no way disproved the results which he had formerly published.

R. L. Smith, *Testing "Glass-Hard" Steels* (American Machinist, European Edition, 1927, vol. 67, Aug. 27, pp. 24E-26E). The Brinell and Vickers' Pyramid methods of hardness testing and their respective readings are compared, and the superiority of the latter method for testing very hard steels is demonstrated.

J. Pomey, *New Machine for Testing Hardness* (Paper read before the International Testing Congress, Amsterdam, 1927).

Hardness Testing Machines (Machinery, 1927, vol. 30, June 9, pp. 312-314; June 23, pp. 373-376; July 14, pp. 471-473; Aug. 11, pp. 597-599; Aug. 18, pp. 627-628; Sept. 29, p. 816). A review of the apparatus available for hardness testing.

E. G. Herbert, *The Work Hardening of Steel by Abrasion* (Paper read before the Iron and Steel Institute, Sept. 1927: this Journal, p. 265).

E. G. Herbert, *Work-Hardening Properties of Metals* (Paper read before the American Society of Mechanical Engineers, Dec. 6-9, 1926 : Mechanical Engineering, 1927, vol. 49, Sept., pp. 980-990). The object of this paper is to correlate with the operation of cutting tools certain well-established and generally recognised facts, the chief being: (1) that metals are hardened by any process which deforms them so as to cause a permanent change of shape while they are at low or moderate temperatures (cold-work); (2) that metals are deformed, and therefore hardened, by cutting tools; (3) that heat is generated by deformation of metals, particularly by metal-cutting operations; and (4) that the degree of hardness induced by working metals, with cutting tools or otherwise, is greatly influenced by the temperature at which the deformation takes place. The author shows the bearing of these facts on the resistance offered by metals to the cutting tool and on the rate of wear of the cutting tool. The relation between the temperature generated in cutting and the heat-resisting properties or "hot hardness" of the tool is touched upon. The limiting factor in the rapid removal of metal is ultimately the temperature generated in cutting in relation to the capacity of the tool to withstand high temperatures. The paper deals more with the heat-producing properties of the work than with the heat-resisting properties of the tool.

C. A. Edwards and K. Kuwada, *The Influence of Cold-Rolling and Subsequent Annealing on the Hardness of Mild Steel* (Paper read before the Iron and Steel Institute, Sept. 1927 : this Journal, p. 245).

L. B. Pfeil, *The Effect of Cold-Work on the Structure and Hardness of Single Iron Crystals and the Changes Produced by Subsequent Annealing* (Iron and Steel Institute : Carnegie Scholarship Memoirs, 1927, vol. 16, pp. 153-210). The work described in this memoir forms the continuation of the research reported by the same author in the Carnegie Scholarship Memoirs for 1926 (vol. 15, pp. 319-380). The structure of cold-worked single iron crystals is shown to depend on the degree of cold-working and the direction of the cold-work relatively to the crystallographic orientation. Six simple types of structure are described, and the conditions for their formation are discussed. The temperature at which recrystallisation occurs in cold-worked iron in the form of single crystals and also of the aggregate depends on the degree of cold-work, but in single crystals it is also dependent on the direction of the cold-work. The recrystallisation of various types of single crystal structures is discussed.

E. W. Fell, *Strain in Steel. Experiments upon the Nature and Detection of Certain Phenomena Observed in Permanently Deformed Steel* (Iron and Steel Institute : Carnegie Scholarship Memoirs, 1927, vol. 16, pp. 101-129). As preliminary experiments, observations were made of the deformation effects produced upon the surfaces of different metals by the Brinell test. The surface strain phenomena which appear around indentations in Armco iron and mild steel were not observed, under the same conditions, on high carbon steels and non-ferrous metals. The

orientation of the surface strain-markings in the Armco iron and mild steel was dependent on the direction of rolling of the material; these materials showed the "bulged out" effect around the actual Brinell hole, but in copper and brass the reverse effect was observed. The conditions necessary for the production of strain-etched figures were examined, and 200° C. was found to be the best temperature for heating strained or cold-worked mild steel before strain-etching; long periods of heating had no additional effect.

F. Körber, *The Cause and Prevention of Defects Appearing During the Working of Mild Steel* (Stahl und Eisen, 1927, vol. 47, July 14, pp. 1157-1166). Several of the most common types of defects which occur during the working of mild steel are described, and typical examples, which have come under the notice of the Kaiser-Wilhelm-Institut for report, are given. Methods for prevention or cure of these defects are indicated. Coarse grain-size, consequent on overheating or recrystallisation of critically cold-worked mild steel within critical annealing limits, leads to a dangerous increase in brittleness. A considerable reduction in toughness follows the ageing of cold-worked steels, and resistance to corrosion is lowered. Unavoidable discontinuities of the ingot, such as segregates, blowholes, and non-metallic inclusions, can, if not suitably treated, reappear as faults in the further treatment: examples of gas welding and pickling blisters in mild steel sheets were given. The importance of the scientific investigation of such defects and the necessity of noting and making use of the results obtained are emphasised if discard is to be reduced. The article is well illustrated with photographs and curves.

M. von Schwarz, *Useful Applications of Recrystallisation* (Zeitschrift für Metallkunde, 1927, vol. 19, Aug., pp. 321-324). After a brief historical review the author describes examples of the utilisation of the phenomenon of recrystallisation for the detection of flaws in materials. Finally, he indicates the relationship between the impact hardness (dynamic hardness test), the depth of recrystallisation, and the temperature.

J. Czochralski, *Historical Contribution to the Problem of Recrystallisation* (Zeitschrift für Metallkunde, 1927, vol. 19, Aug., pp. 316-320). The author notes briefly the principal papers prior to 1921 which played a rôle in the advancement of knowledge concerning recrystallisation.

G. Tammann and W. Salge, *The Determination of the Temperature of the Commencement of Recrystallisation* (Zeitschrift für Metallkunde, 1927, vol. 19, May, pp. 187-188). The angle of friction between the polished surfaces of two bodies, one lying on the other, increases rapidly at a certain temperature; this temperature is that at which recrystallisation begins. At a temperature above the normal a highly polished metal surface will lose its high polish; this roughening of the surface also takes place at the temperature corresponding to the commencement of recrystallisation.

P. Dejean, *Cold-Work by Compression and the Brittleness of Steel. Existence of a Limit of Brittleness* (Génie Civil, 1927, vol. 90, Apr. 2, p. 345; Revue de Métallurgie, Mémoires, 1927, vol. 24, July, pp. 415-417). Test-pieces of mild steel after various heat treatments were subjected to varying amounts of compression; test-bars were then cut out from these pieces and examined for brittleness. It was found that, provided the load did not exceed a certain limit, the resilience of the metal was not sensibly altered by the preliminary compression; but once that critical load was exceeded the resilience dropped rapidly, the passage from the very resilient to the very brittle state being very sudden. The critical load value varied according to the heat treatment.

M. Okochi and M. Okoshi, *New Method for Measuring the Cutting Force of Tools and Some Experimental Results* (Scientific Papers of the Institute of Physical and Chemical Research, Tokyo, 1927, vol. 5, Apr., pp. 261-302). The authors have adopted the Piezo electricity principle of measuring the cutting force of tools, and present the results of their experiments. The composition and heat treatment of the tool steels employed are tabulated. Comparison of three components—i.e. vertical, traversing, and surfacing force—effect of tempering, area of cut, cutting speed, and cutting angle on the cutting force, relation between the cutting force and cutting temperature, and effect of cutting temperature on tool steel, were investigated.

K. Honda and K. Takahasi, *On the Quantitative Measurement of the Cutting Power of Cutlery* (Paper read before the Iron and Steel Institute, Sept. 1927: this Journal, p. 357).

K. von Kerpely, *Silicon Steel as a Structural Material* (Centralblatt für Hütten- und Walzwerke, 1926, vol. 30, pp. 411-414, 425-427, 437-440, 455-459). The properties and uses of the Freund silicon steel are considered. The material is suitable for most kinds of structural work on account of its high tensile properties.

Special Steel for Hudson Bridge (Iron Age, 1927, vol. 120, Aug. 25, pp. 466-468). Particulars are given of the chemical analysis and properties of the alloy steels to be used in the construction of the new suspension bridge for the Hudson River at New York. Two designs are contemplated: one includes the use of wire cables for the main suspension, and the other a chain of forged heat-treated eyebars.

L. Pichard, *The Internal Fissuration of Rails, with an Oval Spot* (Génie Civil, 1927, vol. 90, Jan. 29, pp. 118-123). The author discusses the internal fracture of rails and the formation of oval spots, sometimes silvery and grained in appearance, sometimes silvery and matte, or sometimes matte and coloured, and puts forward hypotheses as to the origin of the various types of spot observed.

F. J. Griffiths, *Alloy Steels in the Railroads* (Proceedings of the Railway Club of Pittsburgh, 1927, vol. 26, Mar. 24, pp. 98-116). The author indicates the many uses of alloy steel in locomotive and railway construction.

H. W. Swift, *The Strength of Cast-In Joints* (Engineering, 1927, vol. 124, Aug. 12, pp. 215-216). The author reports the results of an investigation into the strength of joints made by casting-in steel plates into cast iron. One series of experiments was designed to show the effect of the condition of the surface of the steel, and other tests were made to demonstrate the influence of the shape of the steel surface. Tinning the surface of the steel gave the best results; drilling holes through the steel or splaying it were beneficial in the case of cleaned but untinned metal, but gave little improvement when the steel had been tinned. The tests refer only to static conditions of loading.

Ch. Frémont, *Causes of Explosion of Steel Cylinders containing Compressed Gases* (Génie Civil, 1927, vol. 90, Mar. 5, pp. 239-241). The author reports his investigations into the causes of the explosion of gas cylinders. Illustrations of cracks starting from segregated zones, of striation due to drawing which gave rise to longitudinal failures, and of a rupture which occurred in an autogenous weld, are given.

E. F. Davis and R. J. Peters, *Studies Internal Fractures in Bars* (Iron Age, 1927, vol. 120, Aug. 18, pp. 400-401). The authors discuss the causes of failure of forgings and bar stock, and point out the harmful effect of sulphur.

Testing Engineers in Holland (Iron Age, 1927, vol. 120, Sept. 29, pp. 883, 918; Oct. 6, pp. 941-942). An account is given of the Proceedings of the International Congress for Testing Materials, which was held in Amsterdam in September last, including brief abstracts of the papers presented.

Specifications.—3-in. *Cast Steel Cable Chain* (Engineer, 1927, vol. 144, Aug. 26, p. 237). Brief details of the specification for a cable chain for the Admiralty, and the results of its behaviour under the severe tests which it had to undergo for acceptance, are recorded. The material was cast steel; the proof load was only 15 tons less than the breaking load specified for a similar chain made of wrought iron, and all the other tests were correspondingly more drastic. The breaking load on a three-link sample was to be not less than 306 tons, but the test links withstood 400 tons, the limit of the testing machine, without failure.

British Standard Specification for Tramway Rails and Fishplates (British Engineering Standards Association, No. 2, 1927). In the revised edition of this specification, B.S. Section No. 9 (68·3 lb. per yard) has been omitted, as experience has shown that it is not required, and a new dwarf Section No. 10 (95·4 lb. per yard) has been included, intended primarily for carrying heavy loads on sleeper tracks. The basic Bessemer process for the manufacture of the steel has been eliminated in accordance with the recent decision of the Association.

British Standard Specification for Tubular Tramway Poles (British Engineering Standards Association, No. 8, 1927). This specification for wrought steel tubular poles is a revision of the original specification of 1904. An additional size of poles has been introduced, the classi-

fication now being light, medium, heavy, and extra-heavy. Taper poles are no longer recognised as standard. Various mechanical tests are included, and an appendix gives the approximate weights of poles.

British Standard Specification for Rivets (British Engineering Standards Association, No. 275, 1927). This specification is intended to meet the requirements of structural work (other than boilers), and gives the standard diameters for rivets from $\frac{1}{2}$ in. to $1\frac{3}{4}$ in., inclusive, the manufacturing tolerances on the shanks, and the standard proportions for snap, pan, and countersunk rivet heads. Sketches are included showing the tolerances in the case of (1) rivets up to 5 diameters long, and (2) rivets of greater length.

British Standard Specification for Ball-Bearings and Parallel Roller Bearings (British Engineering Standards Association, No. 292, 1927). Tables of dimensions in inches and mm. are given for the stock sizes of thirty-five types of journal and single- and double-thrust bearings in general use. Only the exterior dimensions of the bearings are dealt with; the specification does not cover the internal dimensions and the design of the bearings, nor the materials which enter into their composition.

British Standard Specification for Round Strand Steel Wire Ropes for Cranes (British Engineering Standards Association, No. 302, 1927).

Report of the German Industrial Standards Committee (Maschinenbau, 1927, vol. 6, July 21, pp. 730-731). Proposed standards for rail sections and fishplates are presented.

A. Steccanella, *Italian Railway Tests of Materials Under their Specifications* (Paper read before the International Testing Congress, Amsterdam, 1927).

Report of Committee A1 on Steel (American Society for Testing Materials, June 1927). New specifications are presented for marine boiler steel, alloy tool steel, and for structural steel for locomotives and cars. Revisions of specifications for steel castings, steel pipe, and alloy steel bolting material for high-temperature service are submitted.

L. Toutain, *Tests in Connection with Specifications for Steel Rails* (Paper read before the International Testing Congress, Amsterdam, 1927).

L. Toutain, *Tests Applied in the Purchase of Rails* (Paper read before the International Testing Congress, Amsterdam, 1927).

Magnetic and Electrical Properties of Iron and Steel.—W. Rohn, *The Effect of Annealing by Stages on the Specific Cold [Electrical] Resistance of Hard-Drawn Wires* (Zeitschrift für Metallkunde, 1927, vol. 19, May, pp. 196-199). The electrical resistance of the hard-drawn wire specimens was first determined at room temperature. The specimens were heated to 100° C. and the resistance at that temperature was determined. The wires were then cooled to room temperature, their resistance measured again, and they were again heated to 200° C. and tested. The testing was carried out by 100° C. stages up to 1100° C.

Among the materials used were chemically pure iron and an alloy containing nickel 62, chromium 15, iron 22, and manganese 1 per cent. The "cold" electrical resistance of iron wire was not altered by the annealing, but that of the hard-drawn iron-chromium-nickel alloy was considerably increased by the annealing and the temperature coefficient was slightly reduced. Annealing at temperatures as low as 100° to 200° C. caused permanent changes in the resistance. The mechanism of this change appears to be, in part at least, independent of recrystallisation.

H. Masumoto, *On the Electrical and Thermal Conductivities of Carbon Steel and Cast Iron* (Science Reports of the Tôhoku Imperial University, Sendai, 1927, vol. 16, pp. 417-435). The author has measured the electrical and thermal conductivities of Swedish carbon steels, cast iron, K.S. magnet steel, and gold. Empirical formulæ for calculating the effect of impurities on the specific resistance and on the thermal conductivity of carbon steels were worked out. The measurements were made on cast iron in the chill-cast condition and again after annealing at different temperatures. From the result of measurements three curves representing the relations of the thermal and electrical conductivities and their ratio to carbon concentration were obtained. By extrapolating the conductivity-concentration curves the following values were obtained for cementite: specific resistance = 14.0, thermal conductivity = 0.017, and the ratio of thermal to electrical conductivity = 0.240. If graphitisation takes place on annealing, the values of the thermal and electrical conductivities, as well as their ratio, increase considerably.

R. L. Sanford and J. M. Barry, *Determination of the Magnetic Induction in Sheet Steel* (United States Bureau of Standards, 1927, Scientific Paper No. 545). The authors describe an investigation undertaken to discover the cause of discrepancies between the Burrows and Fahy Simplex permeameters for the magnetic testing of sheet steels. It is concluded that differences in the results of normal induction tests on sheet steel by these permeameters are to be attributed to the character of the specimen rather than to errors inherent in either method, and that the Simplex permeameter is more sensitive to this than the Burrows. For routine normal induction testing of sheet steel the Fahy Simplex permeameter is the most satisfactory apparatus at present available, provided that the specimens tested are made up of not more than 15 strips (preferably 10) not less than 3 cm. wide.

G. C. Marris, *Magnetism and Magnetic Materials* (World Power, 1927, vol. 8, July, pp. 19-24; Aug., pp. 74-79). Guided by the more recent theories of atomic structure and magnetic behaviour, a descriptive explanation of some aspects of magnetism and a picture of magnetisation and hysteresis in ferro-magnetic materials are given. Possibilities of development suggested by the theory are touched upon. Some of the physical data are tabulated. A large number of ferro-magnetic materials are considered in detail, with the aid of tables of

the principal magnetic data relating to them. The effect of impurities, preparation, annealing, &c., are discussed, and high-frequency and superimposed fields are considered. A bibliography of forty-two references is appended.

K. Honda and H. Endo, *On the Magnetic Determination of the Solidus and Solubility Lines in the Iron-Carbon System* (Science Reports of the Tôhoku Imperial University, Sendai, 1927, vol. 16, pp. 235-244). The solidus and solubility lines in the iron-carbon system were determined from the magnetic susceptibility temperature curve. The paramagnetic susceptibility of steels of various carbon contents decreases linearly with the rise of temperature up to the solidus point or to the solubility point of cementite, and then decreases more rapidly, the curve showing a distinct break at this point. The solidus line thus determined coincides closely with those obtained by Asahara and Kaya, and the solubility line exactly with that obtained by other investigators.

K. Honda and H. Endo, *On the Magnetic Susceptibility of the Iron-Carbon Alloys at High Temperatures, and the Equilibrium Diagram of the System* (Science Reports of the Tôhoku Imperial University, Sendai, 1927, vol. 16, pp. 627-637). The magnetic susceptibility of iron-carbon alloys up to a 5 per cent. carbon content was measured at high temperatures, both in the solid and the liquid states. This susceptibility decreases linearly with the rise of temperature up to the solidus point or solubility line of cementite, where the susceptibility temperature curves show a break or a discontinuity at the point. The susceptibility of molten alloys is independent of temperature. The susceptibility of cementite at high temperatures has been found by extrapolating the susceptibility concentration curves of carbon steel. The solidus, the liquidus, the eutectic, and the solubility line of cementite in iron having been thus magnetically determined, the equilibrium diagram of the iron-carbon system has been revised.

H. Masumoto, *On the Magnetic, Electric, and Thermal Properties of Nickel-Cobalt Alloys* (Science Reports of the Tôhoku Imperial University, Sendai, 1927, vol. 16, pp. 321-332).

G. Hauffe, *Determination of the Resistance of Plates* (Electrotechnische Zeitschrift, 1927, vol. 48, Jan. 27, pp. 106-107).

G. Eichenberg and W. Oertel, *Influence of the Treatment of Transformer Sheets on the Watt Losses* (Stahl und Eisen, 1927, vol. 47, Feb. 17, pp. 262-271); abstracts, *Silicon Steel Transformer Sheets* (Metallurgist, 1927, Sept. 30, pp. 141-142; Journ. I. and S.I., 1927, No. I. p. 948).

Ch. Lapp, *The Fundamental Laws of Magnetic Hysteresis. The Influence of Ageing and of Annealing* (Revue de Métallurgie, Mémoires, 1927, vol. 24, Sept., pp. 496-508).

A. V. De Forest, *Use and Development of Magnetic Analysis in the United States* (Paper read before the International Testing Congress, Amsterdam, 1927).

J. A. Capp, *The Application of Magnetics to the Inspection of Steam Turbine Bucket Wheels* (Paper read before the American Society for Testing Materials, June 1927). The author describes the apparatus used for the routine inspection of steam turbine bucket wheels to determine the homogeneity and soundness of the steel. The method of testing consists in the indication of the presence of defects by changes which they cause in the reluctance of a magnetic current passed through the wheel. The indications are obtained by the use of a high sensitivity galvanometer connected to measuring coils located in the specially designed pole-tips of the electro-magnet between which the wheel is rotated. Typical charts of tests are given, and photographs are shown of typical hidden defects revealed by the apparatus.

Report of Committee A6 on Magnetic Properties (American Society for Testing Materials, June 1927). A proposed tentative method of test for magnetic properties of iron and steel at low inductions for audio and power frequencies is submitted. A suggested nomenclature and definitions of magnetic terms are also presented.

Report of Committee A8 on Magnetic Analysis (American Society for Testing Materials, June 1927). The report includes the following papers: *A Method of Graphic Representation of Magnetic Characteristics*, by A. V. De Forest; *Magnetic Analysis by Means of the Cathode-Ray Oscillograph*, by T. Spooner; *The Duroscope: An Apparatus for the Magnetic Determination of the Durability of Steels*, by J. A. Sams.

Heat-Resistant, Acid-Resistant, and Stainless Steels.—R. S. MacPherran, *Some Tests of a Chrome-Nickel Steel at High Temperatures* (Paper read before the American Society for Testing Materials, June 1927). The tests reported are a continuation of previous work (Proceedings of the American Society for Testing Materials, 1921, vol. 21, p. 852). The present tests were carried out to determine the forging and upsetting properties of a chrome-nickel steel (chromium 7.19 per cent., nickel 18.73 per cent.). At 1400° F. (760° C.) this material not only falls off in strength, but becomes less ductile until a temperature of about 1800° F. (980° C.) is reached. From this point the tensile strength continues to fall off, but the ductility increases to a remarkable degree. The time element is also a factor. A specimen held at 1800° F. (980° C.) for nearly three hours showed about the ductility of a specimen held for twenty minutes at 1850° F. (1010° C.). For straight-line forging it was found that 2200° F. (1205° C.) was satisfactory, but for upsetting it was necessary to go to 2500° F. (1370° C.).

R. Sutton, *A Study of Some of the Causes of Failure in Heat-Resisting Alloys* (Transactions of the American Society for Steel Treating, 1927, vol. 12, Aug., pp. 221–234). The author describes an investigation, the object of which was to determine the causes for failure in heat-resisting alloys, especially the reason why nickel-chromium carburising boxes show so large a variation in their actual life in the furnace. The

composition of the alloy used in the manufacture of these boxes is approximately 60 per cent. nickel, 18 per cent. chromium, and 15 per cent. iron. The principal reasons for failure are enumerated.

W. Rohn, *Heat-Resisting Alloys for Use in Annealing Boxes, Furnace Elements, &c.* (Paper read before the International Testing Congress, Amsterdam, 1927).

Effect of Temperature on the Properties of Metals (Report presented to the American Society for Testing Materials, June 22, 1927: Mechanical Engineering, 1927, vol. 49, Oct., pp. 1111-1114). A progress report of a Joint Research Committee organised by the American Society of Mechanical Engineers and the American Society for Testing Materials. Subjoined to it are two papers. One, entitled "Results of Tests on Thermal Expansion of Four Classes of Steel," by H. J. French, deals with the thermal expansion between 0° and 500° C. of a mild steel, a stainless steel (composition not stated), a chrome-molybdenum steel, and a chrome-nickel alloy containing 0.80 per cent. of iron. The other paper on "Comparative High-Temperature Tension Tests on a Carbon Steel and on a Chrome-Molybdenum Steel," by L. W. Spring and H. J. French, is given in abstract; it describes an investigation of the differences frequently encountered in the results of high-temperature tension tests made on similar steels but in different laboratories. ✕

R. W. Bailey, *The Design of Plant for High-Temperature Service* (Paper read before the North-Western Branch of the Institution of Mechanical Engineers, Apr. 21, 1927: Engineering, 1927, vol. 124, July 8, pp. 44-46). The author discusses the strength properties of steels (particularly creep) at elevated temperatures.

W. Oertel and K. Würth, *On the Influence of Molybdenum and Silicon on the Properties of Rustless Chromium Steel* (Stahl und Eisen, 1927, vol. 47, May 5, pp. 742-753). Twenty melts of 15 per cent. chromium steel were prepared, to which were added carbon in amounts increasing to 0.3 per cent., silicon increasing from 0.24 to 4.70 per cent., and molybdenum from 0.25 to 0.41 per cent. The influence of these elements is summarised as follows. The hardness of hardened chromium steel increases very rapidly with increasing carbon up to 0.3 per cent., but carbon beyond that percentage has little effect on the hardness, and only tends to lower the corrosion resistance of the alloy. The addition of molybdenum does not alter this effect of the carbon. A 15 per cent. chromium steel containing 0.3 per cent. carbon can be hardened to about 600 Brinell units. The series to which silicon was added do not increase in hardness when the silicon exceeds 3 per cent., even when the carbon is high. A slight increase in hardness was noticeable only after quenching from 1100°. As might be expected, soft steels, with over 3 per cent. silicon, show neither the A_1 nor A_3 transformation points. Pure chromium steels, as well as chromium-molybdenum steels, show great toughness, whereas all steels with over 3 per cent. silicon are brittle and become coarse-grained on

heat-treating. Soft steels with about 1 per cent. silicon can be dished to a good depth, but capacity to undergo deformation falls off above 1 per cent. silicon. All the chromium steels were susceptible to hydrochloric acid attack, but resisted acetic acid and sea-water, especially when containing molybdenum. All the high-silicon alloys and silicon-molybdenum alloys were highly heat-resistant.

J. A. Mathews, *Corrosion-Resistant Steels* (Paper read before the International Testing Congress, Amsterdam, 1927).

H. Staeger, *Potential Measurements with Rustless Steel Test-Pieces* (Paper read before the International Testing Congress, Amsterdam, 1927).

W. M. Mitchell, *Stainless Iron and its Application to Chemical Plant Construction* (Industrial and Engineering Chemistry, 1927, vol. 19, Oct., pp. 1171-1175). The physical properties of five typical stainless iron alloys are outlined, and the requirements of a stainless alloy for chemical plant construction are discussed.

Non-Rusting Steels and their Applications (Kruppsche Monatshefte, 1927, vol. 8, May, pp. 103-106). Various brands of Krupp's non-rusting steels are advocated for such purposes as fermenting vats, siphons, dishes, table cutlery, and plates for artificial teeth, for which latter purpose the V2A steel and Wipla metal are particularly suitable.

Composition of Patent Stainless Steels Varies (Iron Trade Review, 1927, vol. 81, Sept. 8, p. 593). A table is given which shows the composition of some of the stainless steels manufactured in the United States, together with the patent numbers, the name of the patentee, the dates of application and issue, and the name of the owner of each patent.

Characteristics of Stainless Steels (American Machinist, European Edition, 1927, vol. 67, Nov. 5, p. 509).

M. Grison and E. Lepage, *Copper-Bearing Steel—Its Resistance to Corrosion* (Revue de Métallurgie, Mémoires, 1927, vol. 24, June, pp. 331-336). The authors quote extensively from the works of previous investigators, and describe further experiments carried out by themselves, both on the corrosion-resisting properties of copper-bearing steels and on their response to mechanical tests, welding tests, rolling tests, &c.

Report of Committee A5 on Corrosion of Iron and Steel (American Society for Testing Materials, June 1927). Reports are presented on the inspection of copper-bearing and non-copper-bearing sheets exposed to the atmosphere and to total immersion. New specifications for zinc-coated sheets are submitted, and new tentative specifications for zinc-coated wire, fencing and fencing materials are also included.

K. Daeves, *The Resistance of Copper Steel to Atmospheric Corrosion* (Stahl und Eisen, 1926, vol. 46, Dec. 30, pp. 1857-1863; abstracts, Metallurgist, Aug. 26, 1927, pp. 121-123; Journ. I. and S.I., 1927, No. I. p. 969).

W. M. Mitchell, *Control of Corrosion—New Alloys* (Industrial and Engineering Chemistry, 1927, vol. 19, Nov., pp. 1253–1256). The development of any single alloy which is universally corrosion-resistant, or even approximately so, is improbable. The most that can be expected is the production of various alloys, or groups of alloys, which will have maximum corrosion-resistance and hence be serviceable for use with some particular class of corrosive agents. In the development of new alloys only those which are true solid solutions, using iron, nickel, or copper as base metals, should be considered.

Acid-Resistant Cast-Iron Alloys.—M. G. Corson, *New Light on Iron-Silicon Alloys* (Iron Age, 1927, vol. 120, Sept. 22, pp. 797–798). The corrosion resistance of iron-silicon alloys (13 to 17 per cent. silicon) is of great importance to the chemical industry for the construction of plant. Duriron, tantiron, corrosiron, thermisilid, elianite, are some of the trade names under which these alloys are known. The brittleness of these alloys is their most important drawback, although methods have been developed by which castings of an excellent smooth surface and possessing fair strength can be obtained as a rule. The author has investigated the various physical features and microstructures of a series of alloys up to 25 per cent. silicon, and has reached the following conclusions: The brittleness of high-silicon alloys is not due to contaminations. They are immune to nitrogen and, to a considerable extent, to oxygen as well. The constitutional features in the range of 4 to 15 per cent. Si are much more complicated than had been supposed by previous investigators. Every alloy up to 14.4 per cent., or slightly below, has to pass through two transitional processes, since there is a wide region both as to temperature and composition where austenitic iron persists in the presence of the body-centred high-silicon phase. This region stretches from approximately 2.5 per cent. to 12.5 per cent. Si at least. All alloys up to 10.5 per cent. silicon, if cast under suitable conditions, will forge without much trouble. They become brittle on cooling, and the more rapid the latter the more brittleness is induced. Alloys up to 9 per cent. silicon can be rendered ductile by a process of slow annealing. The basis of the acid-resisting alloys is the compound Fe_3Si . Beyond its composition (14.5 per cent. silicon) the alloys will show the presence of a secondary constituent, probably Fe_3Si_2 or FeSi , which does not disappear on heat treatment. Its presence produces an increased brittleness.

Use of High-Silicon Iron Alloys in the Chemical Industry (Revue de Fonderie Moderne, 1927, vol. 21, Feb., p. 44). The composition of high-silicon iron alloys for chemical ware is about the following: silicon 14.25, manganese 0.35, phosphorus 0.16, sulphur 0.04, carbon 3.60 per cent. Such an alloy shows a white fracture, and has great hardness, with a close grain. The articles cannot be machined, but must be ground. The heat conductivity is about ten times that of earthenware. The tensile strength is 7 kg. per sq. mm., resistance to

compression 49 kg. per sq. mm., melting point over 1250°C ., scleroscope hardness 49 to 51, shrinkage 1.5 per cent., electric resistance at 0°C . 63.3, and at 18°C . 71.2 microhms per cu. cm. The resistance to acid attack is about fifteen times greater than that of copper.

Thermisilid (Kruppsche Monatshefte, 1927, vol. 8, June-July, pp. 117-121). The properties of a high-silicon cast alloy named "thermisilid" are described. The material is intended specially for chemical ware on account of its high resistance to acid corrosion. It is made in two qualities, the difference consisting in the silicon content. The loss of weight per sq. metre per hour in cold hydrochloric acid, of sp. gr. 1.19, is 0.44 gm. for "thermisilid," and 0.03 gm. for "thermisilid extra." In boiling sulphuric acid, of sp. gr. 1.10, the corresponding figures are 2.5 gm. for "thermisilid" and 0.8 gm. for "thermisilid extra."

Constitution, Metallography, Crystallography.—W. Eilender and W. Oertel, *The Influence of Oxygen on the Properties of Steel* (Stahl und Eisen, 1927, vol. 47, Sept. 22, pp. 1558-1561). The influence of oxygen content on the quality and application of various types of steels was thoroughly investigated. The results obtained definitely prove that oxygen in steel plays a most important part. Its influence has been given precise numerical values as the result of examination of a very large number of melts of ball and ball-bearing steel, special steels for cutlery, high-speed steels, tungsten magnet steels, nickel-chrome constructional steels, transformer sheet and mild steel. It will be possible to bring other properties into line. The results show that the determination of oxygen in steel is becoming more important in industry, and it should be developed till the oxidation and deoxidation processes of the bath can be definitely controlled. On account of the importance of a rapid and reliable method of oxygen determination, considerable expenditure on its development is fully justified. In the case of nickel-chromium steel, annealing brittleness is traceable to oxygen content. As regards magnetic properties, the Würschmidt efficiency figures for a tungsten magnet steel decline as oxygen rises from 0.01 to 0.11. In transformer iron the watt loss is lowest at 0.04 O_2 , but it rises as oxygen increases to 0.10 per cent., and the permeability is lowest when the difference between carbon and oxygen percentage = 0. It increases according as either of these elements preponderates. The quality of ball and ball-bearing steel regularly deteriorates as the oxygen increases. The method of Oberhoffer and his associates was chosen for the estimation of the oxygen.

P. Oberhoffer, *Oxygen in Steel* (Revue Technique Luxembourgeoise, 1927, vol. 19, July, pp. 99-111). The fact that an increase in oxygen does not occur in puddling processes as compared with those in which the bath is melted is explained, according to present knowledge, by the lower solubility of FeO in solid as compared with liquid iron. The oxygen question may be considered from the points of view of quantity

or analytically, the effect on properties, the form in which it is present, and the possible changes in form. The method of reduction by carbon, originally suggested by Tucker, has been developed so that total oxygen may be accurately determined. The Bureau of Standards method is also described, as well as the Ehn qualitative carburising test, in which the case is deeper, and the cementite network clearer in the steel lower in oxygen. The general effects of oxygen in hot- and cold-working are noted, and Eilender's work on the effect of oxygen on various properties is referred to. Four ingots of 1.2, 2.5, 3.4, and 4.7 tons were cast from the same charge and rolled to billets, which were analysed for carbon, silicon, phosphorus, and oxygen. An attempt was made to associate the influence of the ingot section on segregation. It was shown that with increasing size of ingot the segregation of sulphur and phosphorus is greater than that of carbon. If instead of ingot mean section the ratio of height to mean section is used, similar curves are obtained. The maximum segregation of sulphur, phosphorus, carbon, and oxygen in reference to ingot section was also displayed, and oxygen appeared the least segregated under the conditions. Comparisons of the iron-oxygen with the copper- and nickel-oxygen steels were made. The solubility of oxygen in each case appears to be a few hundredths of 1 per cent. Deoxidation was next considered in its theoretical aspects, and the difficulty of laboratory experiments is referred to. Schenck's experimental results are discussed, and the difference of his curves from those of McCance and Le Chatelier is attributed to the probability that the deoxidation products do not separate as MnO , but as a mixture of MnO and FeO , whose proportions alter with the manganese control.

P. Oberhoffer, *The Part Played by Oxygen in Steel* (Zeitschrift des Vereines Deutscher Ingenieure, 1927, vol. 71, Nov. 5, pp. 1569-1576). The foundation of Oberhoffer's attempts to show up the oxygen question was the development of a method of analysis. The hydrogen reduction method was inaccurate, for the temperature employed (1100°C.) only allowed of the reduction of the oxides of iron and manganese. Reduction of the oxides by carbon and volumetric measurement of CO and CO_2 seemed more promising, and a vacuum extraction apparatus was eventually developed. A similar method, but employing a high-frequency furnace, has been developed in the United States. It is now possible to determine separately SiO_2 and Al_2O_3 by the bromide method, and determination of MnO by iodine is promising. The Ehn case-hardening test shows that a steel rich in oxygen behaves quite differently on cementation from a steel poor in oxygen. It seems possible that the time taken for an oxygen determination by the hot vacuum extraction method may be reduced to an hour, which will make the method quicker than a cementation test.

P. Oberhoffer, H. J. Schiffler, and W. Hessenbruch, *Oxygen in Iron and Steel* (Archiv für das Eisenhüttenwesen, 1927, vol. 1, pp. 57-68; 1927—ii.

Stahl und Eisen, 1927, vol. 47, Sept. 15, pp. 1540-1543). The influence of oxygen on the primary and secondary structure of iron and steel and on the properties of alloy steels is discussed. A distinct grain segregation could be observed on the primary etching of vacuum melts of electrolytic iron and iron oxide. As the quantities of carbon and phosphorus present were too small to account for this segregation, it was attributed to the oxygen present in solid solution. The definition of the primary structure appears to depend on the oxygen content, maximum definition being obtained when the oxygen content equals the upper limit of solubility of oxygen in solid iron at room temperature. If more or less oxygen is present the definition is impaired. Secondary etching showed, in overblown steels, large grain, inner crystal structure of ferrite, and large variation in the number of inclusions from grain to grain. Generally it can be said that a steel with high oxygen content shows an uneven, indistinct structure. A series of steels was melted, of which pairs had the same composition. One of each pair was enriched in oxygen by blowing air through it before casting. Oxygen determinations, by the hot extraction process, were carried out on the steels, and the steels subjected to various tests in the cast and forged states. The influence of the various alloying elements on forgeability and red-shortness was investigated. It was shown that red-shortness did not depend on oxygen alone, but the question cannot be completely answered. The oxygen-rich steels were bad, and could only be easily forged when the aluminium content exceeded 0.5 per cent. The forging tests, with a view to obtaining a fibrous fracture, always gave, with the steels rich in oxygen, distinctive fibrous or woody fractures, which were attributed to the primary oxygen segregation. During hardening tests the oxygen-rich steels were inclined to overheat, also to show small hardening limits and coarse martensite or troostite. Overheating tests on the oxygen-rich steel showed coarse grain needle ferrite and general unevenness in structure. Nitride needles were observed in these steels after annealing. Regeneration tests showed no special difference between the steels rich and poor in oxygen. Without exception, the case-hardening tests on the oxygen-rich steels, independent of composition, showed smaller grain, fine rounded cementite network, and small depth of case. With an aluminium content of about 1 per cent., only a very weak hyper-eutectoid zone was attained. During decarburising tests the steels containing oxygen generally showed a thicker scale and decarburised zone.

C. Benedicks and H. Löfqvist, *The Iron-Oxygen System* (Zeitschrift des Vereines Deutscher Ingenieure, 1927, vol. 71, Nov. 5, pp. 1576-1577). The solid phases are Fe, FeO, Fe₃O₄, and Fe₂O₃. A diagram is given, of which the left-hand side is essentially due to Tritton and Hanson. The solubility of oxygen is 0.21 per cent. in liquid iron, 0.05 per cent. in solid α -iron, and rather higher in γ -iron. Other points and curves are carefully considered, and the authors do not expect any

fundamental alterations to the diagram, although the curves may be displaced considerably.

J. D. Gat, *Oxygen in Steel and Non-Hardenability* (Blast-Furnace and Steel Plant, 1927, vol. 15, June, pp. 271-274, 279). The author describes experiments carried out both on a small scale and in an open-hearth furnace by which the probable presence of oxygen as an iron-carbon-oxygen alloy was indicated. He shows that the inability of steel to harden is connected with the presence of this ternary alloy, and discusses the effects of carbon and alloying elements on the characteristics of the metal.

J. D. Gat, *A Study of the Hardenability of Steel* (Forging, Stamping, Heat Treating, 1927, vol. 13, May, pp. 188-191, 195; June, pp. 225-227). Since its introduction in 1921, the McQuaid-Ehn test has played a double rôle. While it has proved exceedingly useful when properly applied, too great an extension of its application has resulted in the over-emphasis of certain "Indices of Abnormality," leading ultimately to confusion. In this connection the author states that grain-size is not a determining factor, nor has previous heat treatment any influence on the irregular hardening or non-hardening of steel. He attributes the property of non-uniform hardening to the presence of oxygen dissolved in the steel, the element forming a eutectoid-like constituent, possibly a compound of iron-carbon-oxygen. The occurrence of oxygen is due to bad furnace practice. The author discusses carburisation in all its details.

S. Epstein and H. S. Rawdon, *Progress in Study of Normal and Abnormal Steel* (Transactions of the American Society for Steel Treating, 1927, vol. 12, Sept., pp. 337-375). The authors define the terms normal and abnormal steel, and describe the characteristics of the normal and abnormal structure in carburising steel and tool steel. It is shown that under certain quenching conditions abnormal steel is more prone to give soft spots than normal steel, but that with drastic quenching in brine or in a sodium hydroxide solution it is possible completely to prevent the formation of soft spots in both normal and abnormal steel. It is also shown that normality and abnormality have their origin in the deoxidation procedure of steel-making, and that in particular additions of aluminium and ferro-vanadium in the mould produce abnormality.

J. D. Gat, *Normality of Steel* (Transactions of the American Society for Steel Treating, 1927, vol. 12, Sept., pp. 376-413). The author discusses the properties of abnormal steel. He concludes that resistance to uniform hardening is caused by a high oxygen content forming a eutectoid alloy with the constituents of austenite.

F. G. Seifing, *Control of Normality in Plain Carbon Steels* (Michigan Engineering Experiment Station, Bulletin No. 13, Sept. 1927). The author describes experiments in which steel bars were made either abnormal or normal by different heat treatment. It is shown that a temperature range exists in the iron-carbon diagram in which complete

dissolution of cementite in steel takes place, and that separation into iron and cementite constituents is difficult even by full annealing treatment.

Sir R. A. Hadfield, *Thermal Changes in Iron-Manganese Alloys Low in Carbon* (Proceedings of the Royal Society, 1927, [A], vol. 115, pp. 120–132). The object of the investigation was the determination of the temperature of the critical magnetic changes in a series of iron-manganese alloys practically free from carbon and containing 1.70 to 38.9 per cent. manganese. Magnetic transformations are confined to manganese alloys with less than 16 per cent. manganese.

V. N. Krivobok, B. M. Larsen, W. B. Skinkle, and W. C. Masters, *Some Characteristics of Low-Carbon Manganese Steel* (American Institute of Mining and Metallurgical Engineers, 1927, Technical Publication No. 24). Low-carbon manganese steels can be manufactured in either basic or acid open-hearth or electric furnaces, available manganese alloys giving any desired composition. The finishing of a manganese heat in the furnace, and the use of silico-manganese for making low-carbon heats, involve special problems in furnace operation which are not yet entirely solved and deserve further study. The lower critical point A_1 (carbon point) on heating to 1350° to 1360° F. is independent of both carbon and manganese content within the limits of 0.07–0.31 per cent. carbon and 1.50–3.15 per cent. manganese. The two upper critical points, designated as $A_{2,3}$, in all probability combined, on heating occur at almost the same temperature, 1480°–1500° F. The A_1 and $A_{2,3}$ points on cooling are lowered as the percentage of manganese increases, but remain approximately the same for the steels containing similar amounts of manganese, independently of carbon content. The sluggishness of transformations is very apparent; in some cases the steels cool through a range of 100 degrees or more before the transformation is complete. It is to be expected that steels of these types, because of slow, sluggish transformation, should be well suited for a large variety of heat treatments. Low-carbon manganese steel may be useful, chiefly in the field of the cheaper alloy steels, where large tonnages are desired of a steel with properties superior to those of ordinary open-hearth carbon steels. A double heat treatment is necessary to bring out the best properties in these steels. If properly heat-treated, low-carbon manganese steels will give values for strength and toughness comparable to those in the lower nickel and nickel-chromium steels. They are characterised by an indefinite yield point, and are markedly insensitive to abuse in heat treatment, especially in regard to ductility. There are indications of superior fatigue and shock resistance, also of superior physical properties at high temperatures in these steels, but the collection of data on this subject has only just begun and no definite statement can be warranted. The writers are inclined to the belief that both the sorbitic network (as described in annealed cast steels) and the banding (in hot-rolled samples) are closely related to the mechanism of solidification. Also, certain treatments, or more precisely, the manner of cooling, are more

prone to develop banding, which is an indication of the complexity of the reaction going on in steels during cooling from high temperatures. It is felt, however, that a careful study of the questions of equilibrium in the solid state at various temperatures and the interactions between different elements must be made before a sound theory can be advanced.

C. R. Wohrman, *Heterogeneity in Iron-Manganese Alloys* (American Institute of Mining and Metallurgical Engineers, 1927, Technical Publication No. 14). The structures exhibited by three typical alloys of pure iron and manganese, containing, respectively, 30, 8, and 3 per cent. manganese, are described and interpreted, attention being called to the fundamental meaning of the Widmanstätten and martensitic patterns in alloys, and to some aspects of photomicrography not generally understood. It is shown that, contrary to universally accepted notions, alloys of iron and manganese are heterogeneous, consisting of several distinct constituents. The similarity of the iron-manganese structures to those of iron-carbon alloys is noted and its significance elucidated. The influence of carbon in imparting valuable properties to alloys of iron has been over-emphasised in the past at the expense of that of other elements capable by themselves of yielding alloys of remarkable properties. Attention is called to the misuse of the term "austenitic" in describing steels containing little, if any, austenite proper, and remedies are suggested to correct this.

R. Scherer, *The Influence of Cobalt, Vanadium, and Manganese on Some Properties of Tool Steel* (Archiv für das Eisenhüttenwesen, 1927, vol. 1, Oct., pp. 325-329). Eutectic carbon steels with increasing manganese, vanadium, vanadium-silicon, cobalt-vanadium, and cobalt were tested for behaviour on hardening, sensitiveness to hardening, volume change on hardening, and retention of cutting edge. The cobalt steel proved very insensitive towards varying conditions of hardening, especially overheating. The alteration in volume on hardening and the sensitiveness to hardening, as determined by the repeated hardening test, were least in the case of cobalt steel. The maximum cutting power, in the case of vanadium steels, was attained with 0.3 to 0.7 per cent. vanadium. The cutting power of cobalt steels rose steadily with the cobalt.

H. Masumoto and S. Nara, *On the Coefficient of Thermal Expansion in Nickel-Cobalt and Iron-Cobalt Alloys, and the Magnetostriction of Iron-Nickel Alloys* (Science Reports of the Tôhoku Imperial University, Sendai, 1927, vol. 16, pp. 333-341). The authors have measured the coefficient of thermal expansion in nickel-cobalt and iron-cobalt alloys, and the change of length by magnetisation in iron-nickel alloys for different fields. The expansion coefficient-concentration curve in nickel-cobalt alloys has one maximum at about 40 per cent. of nickel, and two minima at 30 and 65 per cent. of nickel. In the case of the iron-cobalt alloys, the expansion coefficient has also one maximum at 65 per cent. of iron, and two minima at 47 and 73 per cent. of iron. In

the elongation-concentration curves, two maxima at 20 and 60 per cent. of nickel, and one minimum at 25 per cent. of nickel are observable for every field. In a weak field of 50 gauss, another maximum at 5 per cent. of nickel and a minimum at 15 per cent. of nickel are found. In an 81 per cent. of nickel alloy no change of length takes place for all fields.

T. Kasé, *On the Equilibrium Diagram of the Iron-Cobalt-Nickel System* (Science Reports of the Tôhoku Imperial University, Sendai, 1927, vol. 16, pp. 491-513). The equilibrium diagrams of the systems of iron-nickel, iron-cobalt, and nickel-cobalt have been further studied with regard to the liquidus and solidus parts, using electrolytically deposited pure metals. The conclusion is that the peritectic line in the iron-nickel system includes the alloys having from about 3.5 to 8 per cent. of nickel content at 1510° C., and in the iron-cobalt system those having from 14 to 25 per cent. of cobalt content; in the nickel-cobalt system the liquidus curve is almost linear between the melting points of the two metals.

The equilibrium diagram of the ternary system of iron-cobalt-nickel has been constructed. There exists neither ternary eutectic nor compound; but after complete solidification, a continuous γ solid solution of these metals is formed, though it changes on further cooling. The isothermal curve in the liquidus surface has its lowest point at about 70 per cent. of nickel content on the iron-nickel side (about 1437° C.), and the surface ascends gradually towards the iron and cobalt sides, so that it is a little concave above.

In the completely solidified alloys on the iron and cobalt sides, a polymorphic $\gamma \rightleftharpoons \alpha$ occurs. The beginning and ending surfaces of the transformation are lowered from the A_3 point in the binary system to the temperature of liquid air as the nickel content increases.

The A_2 surface, which passes through the transformation points of cobalt (1115° C.) and nickel (345° C.), is convex above. On the iron side another surface of the A_2 transformation exists, which coincides with the surface of the A_3 transformation on adding a small quantity of nickel and cobalt to the iron.

Both in the case of the binary and ternary alloys the effect of cobalt on the A_3 point in iron is to raise it, and that of nickel is to lower it.

In the binary and ternary alloys the increase of hardness is always found in the alloys in which a rapid lowering of the transformation point takes place.

W. Oertel, *Properties of High-Speed Cobalt Steel* (Zeitschrift des Oester. Ingenieur- u. Architekten-Vereins, 1927, vol. 79, Apr. 29, pp. 158-160).

H. J. French, *Comparison of the Alloying Elements Chromium, Nickel, Molybdenum, and Vanadium in Structural Steels* (Transactions of the American Society for Steel Treating, 1927, vol. 11, June, pp. 845-884, 1000). A brief discussion is given of the effects of chromium, nickel, molybdenum, and vanadium in structural steels.

Comparisons are made of commercial low-alloy steels containing one or more of the specified elements on the basis of their making, shaping, machining, heat treatment, &c. The current high-alloy steels for resisting corrosion or high temperatures are described, and consideration is given to wear as affected by chromium, nickel, molybdenum, and vanadium. The paper is a condensed summary of important characteristics of alloy steels containing the specified elements, and is illustrated by practical applications.

H. M. Boylston, *Influence of Impurities on the Properties of Iron and Steel* (Fuels and Furnaces, 1927, vol. 5, May, pp. 569-576). A brief discussion of the influence of various elements on the properties of iron and steel.

H. M. Boylston, *Effect of Alloys upon the Structure and Physical Properties of Steel* (Fuels and Furnaces, 1927, vol. 5, June, pp. 705-712; July, pp. 841-848). The author discusses the effect of various alloying elements upon the structure and physical properties of steel, with particular reference to heat treatment. Nickel steel, chromium steel, chromium-nickel steel, and vanadium steel are dealt with. The suitability of various alloy steels for different purposes is indicated. The properties and heat treatment of chromium-vanadium steel, tungsten steel, high-speed steel, molybdenum steel, and other commercial alloy steels are also discussed.

C. E. Guillaume, *The Cause of Instability of Nickel Steel* (Archives des Sciences Physiques et Naturelles, 1927, vol. 9, Jan.-Feb., pp. 5-15). The author discusses the action of carbon, manganese, copper, and chromium, and shows that in order to stabilise nickel steel it is necessary to hinder the formation of cementite by combining carbon with a substance for which it has a stronger affinity than for iron, such as tungsten and vanadium.

A. G. C. Gwyer and H. W. L. Phillips, *The Constitution of Alloys of Aluminium with Silicon and Iron* (Paper read before the Institute of Metals, Sept. 1927). The first part of this investigation deals with the constitution of binary alloys of aluminium with silicon and with iron. The eutectiferous nature of the aluminium-silicon system has been confirmed, and special attention is paid to the solubility of silicon in solid aluminium. The position of the Al-FeAl_3 eutectic has been redetermined, and the structure of the alloys lying towards the middle of the constitutional diagram has been, it is thought, elucidated. The second part deals with the constitution of certain of the ternary alloys of aluminium, silicon, and iron, under both equilibrium and metastable conditions. The latter are of considerable practical importance, because they are met with not only in commercial alloys, but also in commercially pure aluminium.

E. H. Dix, jun., and A. C. Heath, jun., *Equilibrium Relations in Aluminium-Silicon and Aluminium-Iron-Silicon Alloys of High Purity* (American Institute of Mining and Metallurgical Engineers, 1927, Technical Publication No. 30). The second part of this paper is confined

to a study of the constitution of aluminium-iron-silicon alloys. The various phases are indicated by ternary diagrams constructed according to the method of Guertler. The existence of the compound FeAl_3 in the binary system aluminium-iron has been confirmed. The low silicon aluminium-iron-silicon alloy designated as the X constituent by other workers is indicated as α (Fe-Si), and the second aluminium-iron-silicon constituent containing more silicon as β (Fe-Si).

T. Murakami, *Further Investigation of the Equilibrium Diagram of the Iron-Silicon System* (Science Reports of the Tôhoku Imperial University, Sendai, 1927, vol. 16, pp. 475-489). Several equilibrium diagrams of the iron-silicon system constructed by other investigators are discussed, and a further revised diagram is proposed. A magnetic transformation constantly taking place at 450°C. is due to the saturated α solution containing 16 per cent. of silicon and is not a eutectoid transformation accompanying the change of phase. A heat evolution occurring at 1020° on cooling is due to the formation of the compound Fe_3Si_2 . The compound FeSi_2 forms a η solid solution ranging from 50 to 51 per cent. of silicon. This compound forms a eutectic with a compound FeSi in alloy, with 34 to 50 per cent. of silicon, while in those with more than 50 per cent. of silicon the former separates from the melt after primary crystallisation of the θ solid solution, consisting mainly of silicon.

H. Hanemann and H. Voss, *A Study of the Systems Iron-Phosphorus, Iron-Silicon, and Iron-Phosphorus-Silicon* (Centralblatt der Hütten- und Walzwerke, 1927, vol. 31, May 11, pp. 245-248; May 18, pp. 259-262; June 1, pp. 287-289).

O. E. Harder and R. L. Dowdell, *The Decomposition of the Austenitic Structure in Steels.—Part V.* (Transactions of the American Society for Steel Treating, 1927, vol. 11, June, pp. 959-974). This part of the paper reports the application of the powder method of X-ray analysis to the study of changes in the structure of steels during heat treatment. The steels used in the investigation are the same as those described in Part I. of this paper. A few tests were made on powders filed from quenched specimens, but the method was discarded as unsatisfactory. The preparation of the powder in the annealed steels, followed by the desired heat treatments and X-ray analysis, gave satisfactory results. The steels were examined in three conditions: (1) as quenched; (2) after submersion in liquid oxygen; (3) after various tempering treatments. The results are in general agreement with the results of the microscopic examination previously reported. The results show, however, that on submersion in liquid oxygen there is not the increase in the intensity of the α lines expected from the amount of martensite formed in larger specimens in the same treatment. The results indicate that certain transformations which produce the martensitic structure give α particles which are too small to be recorded in a crystallogram. Consideration is also given to the position of the carbon in the space lattice of the steels investigated. From a com-

pilation of the evidence from the unit parameters, and a comparison of these values with the values determined experimentally, the evidence indicates that the carbon is held within the space lattice and does not replace the iron atoms. The evidence is more conclusive in the case of austenitic than in the case of the martensitic steel.

O. E. Harder and R. L. Dowdell, *Decomposition of the Austenitic Structure in Steel.—Part VI.* (Transactions of the American Society for Steel Treating, 1927, vol. 12, July, pp. 51–68). The authors attempt to put the results of their investigation into the form of a proposed theory for the hardening and tempering of steel. This theory discusses, in addition to the decomposition of the austenitic structure, the reactions of heating steel above the critical points, the changes which take place while holding at temperature, changes which take place at various rates of cooling, and finally the changes which take place on reheating hardened steels to various temperatures below the critical point for different lengths of time.

K. Honda, *Is the Direct Change from Austenite to Troostite Theoretically Possible?* (Science Reports of the Tôhoku Imperial University, Sendai, 1927, vol. 16, pp. 279–283; see also Journ. I. and S.I., 1926, No. II. p. 417).

K. Honda and K. Iwase, *On the Transformation of Retained Austenite into Martensite by Stress* (Science Reports of the Tôhoku Imperial University, Sendai, 1927, vol. 16, pp. 1–8; see also Transactions of the American Society for Steel Treating, 1927, vol. 11, Mar., pp. 399–412, 473; abstract, Journ. I. and S.I., 1927, No. I. p. 959).

T. Ishigaki, *On the Determination of the Density of Cementite* (Science Reports of the Tôhoku Imperial University, Sendai, 1927, vol. 16, pp. 295–302). The densities of different kinds of carbon steel and cast iron were measured. By extrapolation of the straight line representing the relation between the density and the carbon content to the concentration of cementite, the density of this carbide was found to be 7.662.

F. Sauerwald, H. Neudecker, and J. Rudolph, *Ternary Systems with Iron and Carbon* (Zeitschrift für anorganische und allgemeine Chemie, 1927, vol. 161, Apr. 5, pp. 316–320). The compound Fe_3C , Cr_4C , was prepared and its microstructure examined. It was found that this alloy invariably exhibits a duplex structure, whether slowly cooled or annealed for a long period and quenched. When powdered finely it can be separated into magnetic and non-magnetic fractions.

H. M. Boylston, *The Properties of Iron and Steel as Affected by Composition and Heat Treatment* (Fuels and Furnaces, 1927, vol. 5. Apr., pp. 433–440). A brief discussion is given of the metallography of iron and steel, and the effect of carbon on the physical properties. A table is included giving a number of common uses of steel, arranged according to the carbon content.

H. Brandes, *Theory of Crystal Growth* (Zeitschrift für physikalische Chemie, 1927, vol. 126, Apr., pp. 196–210). The author has developed

a theory of crystal growth for cubic, rhombododecahedral, and octahedral systems, which takes into consideration energy conditions when a new centre of growth is formed on the completed crystal surface.

J. A. M. van Liempt, *Production of Metallic Single Crystals* (American Institute of Mining and Metallurgical Engineers, 1927, Technical Publication No. 15). The methods of making metallic single crystals may be divided into the following groups: (a) from the liquid state; (b) from the gaseous state; (c) electrolytically; and (d) by recrystallisation in the solid state. The methods of Tammann and Czochralski in the first group are outlined. Methods in the second group start with a single crystal, obtained according to another method. This single crystal serves as a nucleus and grows to a larger single crystal. In the electrolytic method which is used by the author, the single crystal is produced at the surface of the metal, the latter being used as a cathode. In the fourth group the methods of Schaller and Orbig, Sauveur and Alterthum, are described.

L. W. McKeehan, *Twinning in Ferrite* (American Institute of Mining and Metallurgical Engineers, 1927, Technical Publication No. 29). The author describes the technique by which twinned crystals of ferrite were formed, etched and their angles measured. The manner of twinning and the effect of conditions on twinning are dealt with, and the paper concludes with a discussion of the stability of twin boundaries.

Y. Shimizu, *A Simple Method for Determining the Crystal Orientation in Metallic Single Crystals* (Science Reports of the Tôhoku Imperial University, Sendai, 1927, vol. 16, pp. 621-625).

R. Forster, *Space Lattice of "Permalloy"* (Physikalische Zeitschrift, 1926, vol. 27, Dec. 15, pp. 829-830).

J. D. Gat, *The Physical Composition of Steel* (Blast-Furnace and Steel Plant, 1927, vol. 15, Apr., pp. 173-176). The author discusses the "fibrosity" of steel. The terms "fibrous" or "reedy" apply to steels which, after fracture, do not show smooth surfaces, but ragged ones, filled with projections and indentations measurable in fractions of an inch. These are caused by the presence of internal planes of weakness along which the metal yields more readily than in the average cross-section. Etching tests showed that fibrous steels invariably had a considerably smaller grain-size; large polygonal grains of approximately the same dimensions were a guarantee of fibre-free fracture, while fibre was always associated with small rounded grains, especially with a tendency to germination, though small-grained structures did not necessarily imply fibre. The tests, by which the cause of fibrosity was traced to the presence of non-metallic films, and the manner of their prevention by suitable modifications of the standard furnace practice, are described.

K. Honda and R. Yamada, *On the Cause of Temper-Brittleness in Steels* (Science Reports of the Tôhoku Imperial University, Sendai, 1927, vol. 16, pp. 307-319). The authors conclude that temper-

brittleness is due to the presence of the carbides separated on the grain boundaries along the solubility line below the A_1 point.

H. A. Dickie, *Magnetic and other Changes concerned in the Temper-Brittleness of Nickel-Chromium Steels* (Paper read before the Iron and Steel Institute, Sept. 1927: this Journal, p. 223).

H. G. Keshian, *Deep Etch Test for Iron and Steel* (Transactions of the American Society for Steel Treating, 1927, vol. 12, Nov., pp. 689-736). The author discusses the deep etch test for iron and steel and describes the types of structure revealed by the method. The factors influencing the results, such as the method of melting, chemical composition, reduction of area, heat treatment, and direction of the fibre in the steel, are dealt with. To secure consistent results and to interpret them properly, the strength and the temperature of the etching acid and the time of immersion should be standardised, and the factors dealt with in the paper should be given due consideration.

F. S. Tritton, *Some Unusual Microstructures in Iron* (Metallurgist, 1927, June 24, pp. 88-90). The author illustrates and discusses two unusual microstructures in an iron specimen. One was produced by quenching a commercially pure iron (carbon 0.016 per cent.) from about 1400° C.; the structure resembles martensite, but obviously cannot be, and the hardness also was practically unaffected by the quenching. The second example is of "sub-boundaries" or double network within a large ferrite crystal in pure remelted electrolytic iron. The sub-boundaries are due to the large "crystal" being really an aggregate of many smaller ones, all almost identically oriented. The observation of only a very few of these unusual cases of "sub-boundaries" is due to the difficulty of revealing them caused by the similarity of the orientation of the component small crystals.

T. Murakami and K. Someya, *On the Durability of the Alkaline Solution of Potassium Ferricyanide as an Etching Reagent in Microscopy* (Science Reports of the Tôhoku Imperial University, Sendai, 1927, vol. 16, pp. 245-264). The alkaline solution of potassium ferricyanide which is generally used for etching steels containing chromium, tungsten, molybdenum, &c., is not very stable, but suffers decomposition with the lapse of time. The effect of concentration on the etching action, the change in the etching action, the decomposition and velocity of the reagent, and the deterioration of the etching action of the reagent, are dealt with.

C. Beck, *The Best Method of Illumination of Metallurgical Specimens with the Vertical Illuminator* (Journal of the Royal Microscopical Society, 1927, vol. 47, June, pp. 116-127). The author deals fully with the theory and practice of the use of vertical illumination of metallurgical specimens under the microscope.

H. Wrighton, *The Photomicrography of Metals* (Journal of the Royal Microscopical Society, 1927, vol. 47, June, pp. 107-115). The paper deals with the correct illumination of the specimen under the microscope. Vertical illumination only is under consideration.

O. E. Romige and J. C. Whetzel, *A Metallographic Polishing Machine* (Transactions of the American Society for Steel Treating, 1927, vol. 12, Aug., pp. 235-238). The authors describe a horizontal disc type of polishing machine built according to their own design. The machine was very smooth running and gave good results.

G. Pirk, *The Metallurgical Microscope* (General Electrical Review, 1927, vol. 30, May, pp. 264-273). The effect of object structure on light waves, limits of resolving power, achromats and apochromats, oculars or eyepieces, illumination and illuminants, plane glass *versus* prism illuminator, are discussed.

Spectrum Analysis.—F. Twyman, *Metallurgical Spectrum Analysis* (Chemistry and Industry, 1927, vol. 46, Apr. 1, pp. 284-287; Apr. 8, pp. 307-312). The author reviews the development of analysis by spectrography and describes modern spectrographs and the methods of using them. The instruments with which Hartley and de Gramont first worked were quartz spectrographs, but for general use a more convenient photographic instrument is required. The author designed a fixed adjustment quartz spectrograph of a type which is in general use at the present time. For the spectroscopic analysis of metals, either the arc or the spark discharge is the most suitable method of producing radiation from a substance. In most cases the arc method is both more simple to use and more effective in detection. The method of quantitative spectrographic analysis is based on the appearance and variation of intensity of selected lines in the spectra of standard samples, the lines showing an increase in intensity as the amount of impurity increases. The lines are readily identified by photographing a comparison spectrum of the impurity itself. Specific examples of the chemical analysis of a number of metals are given. There is no difficulty whatever in estimating manganese or chromium in steel with a high degree of accuracy, and in the case of these and other elements estimations by spectrogram are obtained with great rapidity, information as to all metals present being given at the same time. The method is well adapted to the sorting out of steel and checking purposes.

J. R. Green, *Spectrum Analysis in Metallurgy* (Chemistry and Industry, 1927, vol. 46, Aug. 19, pp. 745-746). The author refers to Twyman's work (see above), and for the benefit of users of spectral methods he emphasises four points with regard to quantitative analyses: (1) A complete analysis by spectral methods is not possible; an illustration shows that the spectra of three lines of widely differing composition are nearly identical. (2) The special province of the method is to estimate small percentages, that is, 1 per cent. or less. (3) The chemical results certainly agree with the spectrographic. (4) The major composition of comparison samples and of the unknown specimens must be approximately the same. The great advantage of the method for metallurgical control work is its rapidity.

W. F. Meggers and F. M. Walters, jun., *Absorption Spectra of Iron, Cobalt, and Nickel* (United States Bureau of Standards, 1927, Scientific Paper No. 551).

Corrosion of Metals.—U. R. Evans, *The Practical Problems of Corrosion* (Journal of Society of Chemical Industry, Transactions, 1927, vol. 46, Aug. 26, pp. 347–355T). The article forms Part I. of a series on the subject of corrosion problems, and consists of a critical examination of the use of inhibitive chemicals.

U. R. Evans and R. T. M. Haines, *The Practical Problems of Corrosion* (Journal of Society of Chemical Industry, Transactions, 1927, vol. 46, Sept. 9, pp. 363–367T). Part II. of the foregoing series contains a study of protective coatings both metallic and paint, with notes on the correct choice of protective material.

J. Newton Friend, *Third Report on the Relative Corrodibilities of Various Commercial Forms of Iron and Steel (Results of Four Years' Exposure in the Bristol Channel)* (Iron and Steel Institute: Carnegie Scholarship Memoirs, 1927, vol. 16, pp. 131–151). Bars of various materials—wrought irons, Armco iron, carbon steels, cupriferous steel, stainless steels, nickel-chrome steels, manganese steel, cast irons—were fitted into a wooden frame and exposed to the action of the sea in the Bristol Channel for four years. The types and degree of the resulting corrosion are discussed, and the results obtained are compared with those from other tests carried out in the laboratory. Despite the differences between the conditions in these two sets of tests, the order of merit of the several classes of metal is the same in both series, being: Polished stainless steels, nickel-chrome steels, wrought irons, cast irons, carbon steels. This order of merit refers only to corrosion under the specific conditions prevailing during the tests; under acid conditions the order would be entirely different. A comparison of the carbon steels and wrought irons suggests that the latter material might prove suitable in marine work for bolts and other articles required to retain their longitudinal strength. Galvanising greatly prolongs the working life of the metal in sea-water; the addition of a little copper appears, in the one test-bar used, to have a similar beneficial effect. The stainless steels resisted sea-water corrosion very well except where the bars fitted into the frame; the nickel-chrome steels were less resistant, and a small amount of tungsten in one bar had no material influence. The manganese steel behaved in practically the same way as the wrought irons. The cast iron bars resisted sea action extremely well, except at their ends, where graphitisation occurred; this is thought to have been accentuated by the presence of organic matter. Removal of the casting skin by machining appeared to make no difference to the cast irons.

The Deterioration of Structures in Sea-Water. Seventh (Interim) Report (Department of Scientific and Industrial Research. London, 1927, H.M. Stationery Office). This publication contains a summary of reports on periodical examinations of the iron and steel specimens

exposed at Colombo, Plymouth, Halifax, and Auckland. It also contains an abstract of a report on "The Corrosion of Some Steel Girders on Birnbeck Pier, Weston-super-Mare," by E. J. McKaig and J. Newton Friend. The deterioration of this structure, which has been in service for twenty years, and which has been regularly cleaned and painted, is remarkable in view of both the severity and irregularity of the corrosion. Chemical analyses do not explain this irregularity, which is considered due to circumstances of the initial painting.

W. H. J. Vernon, *Second Experimental Report to the Atmospheric Corrosion Research Committee British Non-Ferrous Metals Research Association. Section VII.—Iron* (Transactions of the Faraday Society, 1927, vol. 23, p. 113). *Atmosphere of Relatively Low Humidity.*—In an ordinary room atmosphere of low relative humidity, such as obtains under conditions of artificial heating, the process of rusting is controlled entirely by suspended solid impurities in the atmosphere. The weight-increment curve is concave about the time axis, *i.e.* the rate of attack falls off with increasing time. Rusting may be stopped entirely either by filtering the air or by screening the specimen behind a single thickness of muslin. During such time as the iron is exposed to an atmosphere screened from solid particles, it develops a protective film in an analogous manner to other metals (*i.e.* copper and lead). On subsequent (normal) exposure this film definitely resists attack for a time, but then breaks down at certain points, following which the localised attack proceeds at an accelerating rate.

Atmosphere of Relatively High Humidity (such as may obtain in an ordinary room which is not artificially heated).—In the presence of suspended solid particles as before, and if the relative humidity is sufficiently high, the rate of attack accelerates from the start owing to the deposition of particles and concomitant precipitation of moisture. (Rusting may still be prevented by screening behind muslin.) If iron, already covered with (dry) rust, is exposed to an atmosphere of the necessary relative humidity (actually not more than 70 per cent.), an extraordinary acceleration in the rate of attack at once takes place. These phenomena have been observed equally upon ingot iron of commercial quality, highly purified iron, and upon steel containing 0.5 per cent. C.

Atmosphere Saturated with Water Vapour.—Under conditions prevailing at the dew-point, rusting of the iron takes place in the absence of suspended solid particles. The rate of attack accelerates from the start, yielding a curve which is concave about the weight axis.

Honegger, *Erosion in Turbine Blading* (B.B.C. Mitteilungen, Mar., 1927: abstract, Metallurgist, 1927, Apr. 29, pp. 63–64). The author has carried out experiments in an attempt to determine the causes and nature of erosion and the resistance to this form of deterioration offered by various materials. In his first tests steam was used, but it was impossible to control separately its various variables, such as pressure, velocity, and moisture content. In the later tests

water-jets with low velocities were used, and the specimens, mounted on rotating shafts, were impelled against the water-jets, the relative velocity of impact thus being known.

Duffek, *The Influence of Carbon Content on the Corrosion of Special Steels* (Stahl und Eisen, 1927, vol. 47, Aug. 18, pp. 1376-1377). The author, in a lecture on May 5, 1927, to the Imperial Committee for Protection of Metals, gave the results of comprehensive tests to determine the influence of carbon on the corrosion of special steels in sulphuric and in nitric acid. The results for carbon steels were unsatisfactory. In annealed chromium steels corrosion was more rapid with increasing carbon. These steels in the hardened state are more resistant. Chromium steels proved specially resistant and passivity phenomena were observed in some of them.

J. S. Vanick, *Deterioration of Structural Steels in the Synthesis of Ammonia* (Transactions of the American Society for Steel Treating, 1927, vol. 12, Aug., pp. 169-194). The author discusses the deterioration of steel during the direct synthesis of ammonia from hydrogen and nitrogen. Early experimental work showed that plain carbon steels were liable to rapid deterioration. A group of ten commercial steels, exposed to the hot gases for four months, showed that all the steels were susceptible to attack. It was found that the carbon steels decarburise and fissure readily. Nickel steels were deeply penetrated, but showed a high residual strength in spite of the presence of fissures. Chromium steels deteriorate rapidly if the carbon content is high, but are resistant if the carbon is low. Tungsten and nickel reinforce the deterioration resistance of chromium steels if the latter are low in carbon. Tests carried out on a series of chromium-vanadium steels showed that low carbon was desirable. A suitable steel should contain at least 2.25 per cent. of chromium, with not more than 0.30 per cent. of carbon. The addition of vanadium gave no perceptible improvement. An explanation of the mechanism of the deterioration of the steels is advanced. Evidence that carbon was eliminated during exposure was secured. Decarburisation, fissuring, and the presence of combined nitrogen in some of the steels are accounted for, first, by the presence in the gas mixture and the penetration into the steels of molecular hydrogen; second, by the injection of "actuated" hydrogen released from catalysed reactions; third, by the inflation of the crystal lattice by hydrogen "activated" during its infiltration into the steels; fourth, by the more rapid diffusion of hydrogen in the filtration of the gas mixture through the steel, causing localised enrichments of ammonia which accomplish the formation of nitrides, which are, in turn, decomposed. Internal decarburisation and the occurrence in a nitride-decomposing gas of nitrogen-rich layers in the chromium steels, are provided for in a cyclic reaction theory of nitride formation and decomposition.

S. W. Parr and F. G. Straub, *Embrittlement of Boiler Plate* (Paper read before the American Society for Testing Materials, June 1927).

The investigation described is a continuation of one of which the preliminary results were reported in Proceedings of the American Society for Testing Materials, 1926, vol. 26, Part 2, p. 52. The term "embrittlement of boiler plate" is defined as the intercrystalline cracking in the riveted areas. The results of laboratory tests on the reproduction of embrittlement by means of caustic solutions are given. These show that embrittlement will not proceed in the absence of a stress above the yield point. Increased temperature causes the cracking to proceed at a faster rate in much more dilute solutions than heretofore used. Various steels have been tested to find if any one is resistant to this attack, and no steel has been found that is resistant to any marked degree. Heat treatment of the boiler plate does not stop the cracking. The inhibiting effect of sodium sulphate has been studied at a pressure of 500 lb. A theory covering embrittling action is also presented.

L. H. Callendar, *Influence of Boundary Films on Corrosive Action* (Proceedings of the Royal Society, 1927, vol. 115, A, pp. 349-372). Local corrosion of metals is governed by boundary films of a solid, liquid, or gaseous nature on the metal surface and is liable to occur wherever a metal tends to form oxide films or scales of a higher potential than the metal itself.

E. L. Chappell, *Influence of Rust-Film Thickness upon the Rate of Corrosion of Steels* (Paper read before the American Chemical Society, Sept. 5-11, 1926 : Industrial and Engineering Chemistry, 1927, vol. 19, Apr., pp. 464-467). The paper presents data which indicate the conditions under which the rust films on steels seem to determine the corrosion rate quantitatively, external factors being constant. The author concludes that a very thick film is required to decrease appreciably the corrosion rate of copper steels, and that more easily corroded steels have a much longer life when protected by even a thin film of corrosion product. This indicates the conditions under which copper-bearing steels under water would not be superior to ordinary steel—namely, where thick films are formed. On the other hand, where the rust film is removed, as by mechanical means, copper-bearing steels are likely to be more resistant. In addition, it must be concluded that the common practice of removing rust accumulations from iron surfaces, such as inside water heaters and tanks, is likely to increase greatly the attack on the metal ; the importance of rust-film thickness is recognised in practice, when, for example, it is pointed out that a tubular condenser will last longer if not cleaned of rust. In cases of heavy metals, such as cast iron, a thick film may be allowed to build up and corrosion be practically stopped.

H. S. Rawdon, *Intercrystalline Corrosion of Metals* (Industrial and Engineering Chemistry, 1927, vol. 19, May, pp. 613-619). The author shows that intercrystalline corrosive attack of metals when due to corrosion alone is generally related to some structural features peculiar to the metal. In general, metals become embrittled more rapidly when under high stress, and to prevent corrosion as far as

possible the application of protective coatings is recommended in such cases.

T. Fujihara, *Paradox of Corrosion and Protective Film Theory* (Industrial and Engineering Chemistry, 1927, vol. 19, Sept., pp. 1008-1009). In a previous paper the author concluded that the uncorroded rim outside a drop of water on iron is due to the formation of a protective film of the metal as corrosion product. Therefore, the more corrosion product there is the more protection is given the metal. The results of an experiment to determine whether electrolytic iron or Armco iron produces the more protective film when subjected to corrosion by water show that the protective film produced by corrosion after a certain time will reverse an original rate of corrosion of metals, thus bringing out a paradox that the more favourable the condition for corrosion the less would be the corrosion. Evidently this contradicts the electrolytic theory, which claims that the pure metal corrodes less than the impulse metal. The foregoing statement, however, does not mean that the total corrosion of Armco iron is less than that of electrolytic iron. The experiment proved that Armco iron was protected by corrosion products better than electrolytic iron after a certain period of time in which both had begun to corrode.

G. A. Tomlinson, *The Rusting of Steel Surfaces in Contact* (Proceedings of the Royal Society of London, 1927, A, vol. 115, pp. 472-483). The author describes experiments carried out to investigate the rusting which occurs when steel surfaces are rubbed together. He shows that pressure alone is not sufficient to cause the oxidation, and that relative tangential motion is necessary. Oxidation of the steel will occur also if the object pressed and rubbed against it be a fused bead, such as a glass sphere. The author disagrees with the theory that the surfaces in contact become crushed, and that the minute particles of powder then oxidise rapidly, and suggests that the phenomenon is a result of molecular cohesion. Other experiments, in which the surfaces were covered with a smear of vaseline or castor-oil, showed that oxidation did not occur until the pressure was raised considerably, and a study was made of the stresses at which the film separating the surfaces was ruptured.

K. H. Logan, *Bureau of Standards Soil Corrosion Investigation* (American Foundrymen's Association, June 1927). In 1922 the Bureau of Standards, in co-operation with the Department of Agriculture and a number of pipe manufacturers, undertook an investigation of the relation of soils to corrosion, the primary purpose of which was to ascertain the extent to which soil action might account for observed deterioration of buried pipes. The present paper is the second progress report on unprotected pipe. Tables are presented showing the rates of corrosion and pitting of iron and steel pipes after burial for periods of one to two years. The data presented indicate quite definitely that the corrosion of buried metallic structures is largely influenced by the physical or chemical characteristics of the soil, or, at least by some

phenomena associated with the location of the structure. While the corrosiveness of several soils must be recognised, attention should also be called to the fact that in the majority of soils the rate of corrosion is low and in some it is practically negligible. The hydrogen ion concentrations and water soluble salts of most of the soils under investigation are tabulated.

H. Reininger, *Corrosion of Metals and Its Relation to the More Important Cast Alloys* (Die Giesserei, 1927, vol. 14, Aug. 6, pp. 541-544).

R. Stumper, *Contribution to the Theory of the Process of Rusting* (Korrosion und Metallschutz, 1927, vol. 3, Aug., pp. 169-171).

I. Ginsberg, *Corrosion in the Gas Industry* (American Gas Journal, 1927, vol. 126, Apr. 9, pp. 353-356).

Corrosion (Zeitschrift für angewandte Chemie, 1927, vol. 40, Jan., pp. 96-103). Symposium of papers presented at the 1926 meeting of Reichsausschuss für Metallschutz.

H. J. Donker and R. A. Dengg, *The Corrosion of Iron and its Anodic Polarisation* (Polytechnisch Weekblad, 1927, No. 40, p. 775; No. 47, p. 912; Korrosion und Metallschutz, 1927, vol. 3, Oct., pp. 217-222).

H. Sarrade, *Electrolysis of Mains by Stray Currents from Tramway Systems* (Paper read before the Annual French Gas Congress, 1927: abstract, Gas Journal, 1927, vol. 179, Aug. 24, pp. 449-451). The author discusses the electrolytic corrosion of gas mains of various materials by stray electric currents from tramway systems.

A. Bolzinger, *A Study of the Phenomena of Electrolytic Corrosion of Mains* (Gas Journal, 1927, vol. 197, Aug. 21, pp. 499-501; Sept. 7, pp. 551-553; Sept. 14, pp. 628-629; Sept. 28, pp. 754-756).

U. R. Evans, *The Passivity of Metals. Part I.—The Isolation of the Protective Film* (Journal of the Chemical Society, 1927, May, pp. 1020-1040). When metals become passive they are found to be covered with a film which is too thin to give interference tints, but which can be removed and thus rendered visible by dissolving away the metal below it. This film is the cause of the passivity. The author describes the films formed on several metals, their production by various agents, and their behaviour. He discusses the effects of chlorides on passive iron, water-line attack on passive metal, the action of nitric acid on electrolytic iron, &c., and deals briefly with aluminium and copper also.

F. N. Speller, E. L. Chappell, and R. P. Russell, *Derusting Piping* (Paper read before the American Institute of Chemical Engineers June 3, 1927: Iron Age, 1927, vol. 120, July 7, p. 31). The authors describe a method of removing rust from a cold water-pipe system. The method is thought to be equally applicable to removal of rust from condensers, boilers, and other systems. The rust is dissolved in acid, rendered inert toward the metal by the addition of inhibitors. The solvent used was a strong hot solution of hydrochloric acid, prepared by mixing commercial acid with hot water, the iron being dissolved as ferrous and ferric chloride.

Electroplating and Coating of Metals.—F. M. Dorsey, *Degasification of Metals and its Relation to Corrosion* (Industrial and Engineering Chemistry, 1927, Nov., vol. 19, pp. 1219–1225). A description is given of the process devised by C. P. Madsen for the degasification of metals and for the subsequent plating of these metals with nickel. In the degasification of the base metal, such as iron and steel, the metal is used as the anode in a bath of 66° Bé. sulphuric acid at ordinary temperatures. The cathode may be either the steel container tank or another sheet of steel. Acid of less than 85.4 per cent. does not work satisfactorily, and while fuming sulphuric acid could be used, it is impracticable to handle acid of greater strength than 98 per cent. After degasification it is highly important to remove completely all traces of acid from the metal before plating. Under certain conditions a nickel plate which is soft, ductile, annealable, and malleable may be produced, thus permitting rolling, drawing, or other mechanical treatment. Sheets have also been degasified, nickel-plated, and then given a heavier coating of chromium than is ordinarily possible without the peeling of the nickel coating, and such plates have been pressed into finished shapes without producing flaws in the coating.

W. Pfanhauser, *The Bosse Process of Chromium Plating* (Metal Industry, 1927, vol. 31, Oct. 7, pp. 315–316). A comparison is first made of German and American practice, and this is followed by a brief account of the Bosse process for eliminating hydrogen from the chromium deposit. The plated articles are suspended in a vessel as though for electroplating, and the whole is then placed in a vacuum vessel which is evacuated. The introduction of high-pressure a.c. causes the articles to emit light, and at the same time the hydrogen is removed. In 15 minutes the process is complete, as is shown by suitable vacuum instruments and also by a change in the light emitted by the objects. The hydrogen is withdrawn also from the basis metal.

H. E. Haring and W. P. Barrows, *Electrodeposition of Chromium from Chromic Acid Baths* (United States Bureau of Standards, 1927, Technologic Paper No. 346). A detailed study is made of the chromic acid plating solution and of the conditions for its operation and control. The three principal types of chromic-acid bath which have been developed during the past seventy years are shown to be identical not only in initial behaviour, but also in ultimate composition. The recent commercial success of chromium plating is therefore attributed not to any changes which have been effected in the composition of the bath, but to its more careful operation and control. It was found that minor improvements could be effected in the throwing power of chromic-acid baths, but that there appears to be little possibility of materially improving this property, which has hindered the more general adoption of chromium plating.

O. P. Watts, *Anodes for Chromium Plating* (Paper read before the American Electrochemical Society, Sept. 1927). Various materials,

including chromium, lead, iron, nickel, ferro-silicon, and certain other ferrous alloys, were tried out in a chromic-acid plating bath. It was found that lead anodes are the most serviceable for long-continued operation of the bath.

S. Wernick, *Recent Developments in Chromium Plating* (Metal Industry, 1927, vol. 31, Sept. 30, pp. 291-293; Oct. 7, pp. 313-315; Oct. 14, pp. 345-346). A review of recent work.

D. H. Killeffer, *Chromium Plating—A New Aid to Industry* (Industrial and Engineering Chemistry, 1927, vol. 19, July, pp. 773-776). The author reviews the properties of chromium, the conditions under which it is electroplated, and its useful and decorative applications. He also adds a word on the subject of the situation as regards the patents covering some of the plating processes.

Rust-Proofing Processes (American Machinist, European Edition, 1927, vol. 66, July 9, p. 945). Brief descriptions are given of the Udylyte and Cadalyte processes. Both are essentially cadmium-plating processes, but in the former the plating is followed by baking in order to cause the cadmium to penetrate the steel and form an alloy case.

C. H. Humphries, *Cadmium Plating Resists Rust* (Iron Age, 1927, vol. 120, Aug. 18, pp. 401-402). The author deals with the electroplating of cadmium, and points out that certain addition agents in the electrolytic bath produce deposits which have a high lustre and a good throwing power. A table is included giving some of the resistance values of cadmium coating in salt-spray tests.

G. B. Hogaboom, *Twenty-Five Years of Electroplating* (Paper read before the American Electrochemical Society, Apr. 1927). The author briefly reviews the developments in electroplating during the past twenty-five years.

K. Pitschner, *A Rapid and Practical Method of Applying the Ferroxyyl Test to Protective Coatings* (Paper read before the American Society for Testing Materials, June 1927). The author describes a rapid test for detecting pinholes in metallic coatings, such as nickel or chromium plating. In the method described a test paper coated with the reagent is used.

E. A. Ollard, *Testing Protective Coatings* (Metal Industry, 1927, vol. 31, Oct. 28, pp. 385-387; Nov. 4, pp. 416-418). The author first discusses the question of the corrosion of coated articles, and indicates the corroding factors generally present in actual service, touching on the difficulty of imitating working conditions in laboratory tests. He suggests two types of corrosion tests which he thinks could be sufficiently standardised to give comparable results. In the one, the flat test-pieces are placed in an inclined position in a closed box or cupboard in which the temperature would be suitably controlled so as to imitate diurnal changes; liquid spray at suitable intervals would simulate rain, and dust would also be introduced; the corrosive action of the atmosphere would be reproduced by acid vapours, which

arrangement would also accelerate the test. The second test is designed to introduce the erosion factor. The corroding liquid would be contained in a ring-shaped trough around the sides of which the test-pieces would be hung. A paddle carried on a rotating arm would stir the liquid round the trough, thus imitating the conditions found in pipes, tanks, ships' bottoms, &c. The author suggests that the time taken for the coating to fail should be regarded as the measure of the protection afforded by it.

E. F. Kohman and N. H. Sanborn, *The Tin-Iron Alloy in Tinplate* (Paper read before the American Chemical Society, Apr. 11-16, 1927 : Industrial and Engineering Chemistry, 1927, vol. 19, Apr., pp. 514-518). A series of parcels of tinplate with varying amounts of tin-iron alloy in the coating were made by varying the time and temperature of the dipping of the plate in the tin, and experiments were made to test the resistance of the tin cans made from the sheets to attack by fruits packed in them. The structure of the coating is described and discussed. One way in which a thicker coating appears to give beneficial results is that the extra tin seems to "lubricate" the metal during the drawing operation, so safeguarding the protective coat.

F. N. Speller and E. L. Chappell, *Practical Application of Inhibitors in Pickling Operations* (Chemical and Metallurgical Engineering, 1927, vol. 34, pp. 421-423). Small amounts of certain materials added to acid solutions greatly decrease their rate of attack on metals without markedly slowing down their rate of solution of oxide. This effect is more marked with high acid concentration than with low, and is less marked at high pickling temperatures. This inhibiting action is apparently catalytic.

W. H. Ibbotson, *Some Notes on the Pickling of Steel* (Industrial Chemist, 1927, vol. 3, Apr., pp. 147-148). The author reviews the outstanding points in the pickling of steel.

H. Altpeter, *The Galvanisation of Iron and Steel Wire* (Wire, 1927, vol. 2, July, pp. 233-235, 248-252 ; Aug., pp. 272-273, 282-285 ; Sept., pp. 306, 324-325).

Pot Galvanising on the Pacific Coast (Iron Age, 1926, vol. 120, Oct. 13, pp. 1016-1017). The method of pickling and galvanising of hot-water boilers at an American plant is briefly described. The use of deep pickling vats permits the emersion of the boilers in an upright position.

E. D. Timmerman, *Galvanising* (Iron and Steel of Canada, 1927, vol. 10, May, pp. 127-129). The author describes briefly the galvanising, sherardising, electro-galvanising, and Schoop processes, and describes the structures of the coatings produced.

Enamel Symposium (Journal of the American Ceramic Society, 1927, vol. 10, June, pp. 451-462). The following papers composing the symposium are given : *Standardising Shop Practices Relative to Making and Application of Steel Ground Coat Enamels*, by F. G. Jeager. *Making and Firing of Sheet Steel Ground Coats*, by R. D. Cooke.

Emphasising the Control of Methods Used in the Making and Firing of Ground Coats for Sheet Steel, by R. Fellows. *Method of Control for Application of Ground Coat Enamel*, by A. Jennings.

Light Coloured First-Coat Enamels for Sheet Iron (United States Bureau of Standards, 1927, Technical News Bulletin No. 122, p. 10). An investigation is in progress at the Bureau of Standards to eliminate the necessity for the dark first coat of enamel (base coat) either through the development of a light-coloured enamel, which by virtue of its composition has an adhesiveness comparable to that of the cobalt base coat, or through improving the technique of application. Several different opacifying materials added in the raw state have been studied, and included tin oxide, zirconium silicate, zirconium oxide, and sodium antimonate.

F. W. Manker, *Proper Fusing of Enamel Vital* (Iron Age, 1927, vol. 120, Sept. 1, pp. 531-534). The practice at the plant of the Detroit-Michigan Stove Co., Detroit, for the japanning and enamelling of gas-stoves is described and illustrated.

J. E. Hansen, *The Effect of Mill Practice on the Working Properties and Finish of Vitreous Enamels* (Journal of the American Ceramic Society, 1927, vol. 10, July, pp. 517-523).

H. Nathusius, *The American Electric Enamelling Furnace* (Centralblatt der Hütten- und Walzwerke, 1926, vol. 30, pp. 310-311). A description is given of the Hagan electric enamelling furnace.

W. J. Miskella, *The Application of Japan by Spraying* (Fuels and Furnaces, 1927, vol. 5, Apr., pp. 487-490). The development of equipment for the spraying of japan is dealt with.

W. J. Miskella, *The Spraying Method of Applying Japan* (Fuels and Furnaces, 1927, vol. 5, May, pp. 623-626). A brief description is given of the design and operation of spraying equipment. The spray gun, air transformer, and pressure container are dealt with.

W. J. Miskella, *The Selection and Operation of Air-Compressing Equipment for Japanning* (Fuels and Furnaces, 1927, vol. 5, June, pp. 751-762). The author discusses the proper types of air-compressing equipment to be used in the japanning of iron and steel.

W. J. Miskella, *The Spray Booth for Japanning Operations* (Fuels and Furnace, 1927, vol. 5, July, pp. 883-885). The author discusses briefly the development of the spray booth, the exhaust systems, and mechanical handling devices in japanning.

W. J. Miskella, *Water Japanning Process* (Fuels and Furnaces, 1927, vol. 5, Aug., pp. 1001-1003). A brief discussion is given of the composition and properties of water japan, its concentration, testing, method of application, and baking requirements.

W. J. Miskella, *The Application of Water Japan* (Fuels and Furnaces, 1927, vol. 5, Sept., pp. 1203-1206, 1216). A brief discussion of the methods and equipment employed for applying water japan. There are two general methods used—the electric-dip method and the hot-dip method.

W. J. Miskella, *Japanning Ovens* (Fuels and Furnaces, 1927, vol. 5, Oct., pp. 1369-1372). The general requirements of japanning ovens are briefly discussed.

B. C. Collier, *Result of Guniting Encasement on Structural Steel* (Proceedings of the Engineers' Society of Western Pennsylvania, 1927, vol. 43, Feb., pp. 80-87). As a corrosion protection for structural steel Portland cement has been a failure; its usual mode of application permitted an air film to remain in contact with the metal, and water was also often able to penetrate. Guniting is the name given to a concrete or mortar protective coating applied by means of the cement gun. The paper reports the results of tests made to determine the efficiency of guniting as a protection against corrosion and fire, and to show its effects on the strength properties of sections coated with it.

General Metallurgy.—H. C. H. Carpenter, *Some Recent Services of Metallurgy to Engineering* (Thirty-Third James Forrest Lecture delivered at the Institution of Civil Engineers, May 3, 1927: Engineer, 1927, vol. 143, May 6, pp. 490-491; May 13, pp. 520-522; Engineering, 1927, vol. 123, May 6, pp. 555-556; May 20, pp. 625-626).

P. Goerens, *Special Steels and their Relation to the Production Processes* (Kruppsche Monatshefte, 1927, vol. 8, Jan., pp. 1-8; Feb., pp. 25-48; abstract, Metallurgist, 1927, May 27, pp. 75-78). The author discusses the nature and properties of special steels in relation to the purposes to which they are to be applied, and as distinct from ordinary commercial steels. Reference in particular is made to the occurrence of inclusions, the mode in which they are formed and their influence on the quality of the steel, the details of the processes by which all kinds of steel are produced, and methods of testing. Closer co-operation, particularly in the study of metallurgical problems, between the users and manufacturers is strongly advocated.

C. H. Plant, *Metallurgical Theories for the Practical Iron and Steel Man* (Iron and Steel Industry, 1927, vol. 1, June 3, pp. 52-54; July 1, pp. 81-84; Aug. 5, pp. 96-99; Oct., pp. 18-20; Nov., pp. 55-57). A series of simple and practical articles intended for those who have not the leisure or opportunity for mastering the complex theories underlying the metallurgy of iron and steel, as usually set forth in textbooks. A beginning is made by marshalling plain facts as a preliminary to explanations of the theories which have been built up on these facts.

CHEMICAL ANALYSIS.

Analysis of Iron and Steel.—*Report of Committee A3 on Cast Iron* (American Society for Testing Materials, June 1927). New methods of sampling and chemical analysis of pig iron and cast iron are presented.

M. Cymboliste, *Method of Rapid Analysis of Cast Iron* (Revue de Fonderie Moderne, 1927, vol. 21, Apr. 25, pp. 82-85). The author describes methods for the simultaneous determination of silicon, phosphorus, and manganese, and for the determination of carbon and sulphur. The solutions and liquors used for these determinations are given.

A. Staderer, *Critical Investigation of the Methods for the Determination of Silicon in Pig Iron and Steel* (Stahl und Eisen, 1927, vol. 47, June 9, pp. 966-969).

J. Ciochina, *On the Problem of Sulphur Contained in Cast Iron and Steel* (Chimie et Industrie, 1927, vol. 17, Mar., pp. 383-384). The results reported here form a continuation of work published previously (see Journ. I. and S.I., 1927, No. I. p. 915). The author describes in detail his procedure in estimating sulphur by the H_2S method, and shows that with a cast iron carrying about 0.15 to 0.2 per cent. of sulphur, 0.005 to 0.009 per cent. of that element is not carried over to the collecting vessel as H_2S , but remains in the reaction flask as elemental sulphur. Estimation of sulphur by combustion in oxygen always gives slightly higher results, because in this case the free sulphur is oxidised as well as that in combination with the iron and manganese. He describes an experiment in which two samples of molten pig iron were drawn, one immediately after the other, from the same part of the same cast. One was quenched and one was cooled slowly in air; the former contained 0.148 per cent. of sulphur and the latter 0.106 per cent. He attributes this difference to the rapid cooling of the former sample preventing the sulphur, present as vapour, from escaping, the sulphur later combining with the iron to form a sulphide, a small portion remaining in the elemental state. The author attributes the presence of elemental sulphur in pig iron to a reaction in the blast-furnace by which sulphur dioxide is reduced by carbon.

W. Herwig, *Determination of Sulphur in Steel* (Chemiker Zeitung, 1927, vol. 51, p. 275).

G. Thanheiser and P. Dickens, *On the Determination of Carbon in Iron and Steel by the Baryta Method* (Mitteilungen aus dem Kaiser-Wilhelm-Institut für Eisenforschung, 1927, vol. 9, pp. 239-245). The

authors describe a new apparatus for the estimation of carbon in steels by the baryta method, in which the titrimetric and gravimetric analyses may be carried out simultaneously. The method was originally developed for dealing with low-carbon steels, but was then extended to include also high-carbon steels and ferro-alloys. The time required for the titrimetric assay is so short that it may be used as a "rapid method."

P. Oberhoffer, *On Oxygen in Steel* (Revue Technique Luxembourgeoise, 1927, vol. 19, No. 4, pp. 99-111). The difficulties encountered in estimating the oxygen in steels by the methods employed by the author, by the U.S. Bureau of Standards, and by Ehn are enumerated and compared, and the effects of dissolved oxygen on the properties of steels are discussed. The constitution of steels containing oxygen is also dealt with.

G. Thanheiser and C. A. Müller, *The Influence of Silicon on the Estimation of Oxygen in a Current of Hydrogen* (Mitteilungen aus dem Kaiser-Wilhelm-Institut für Eisenforschung, 1927, vol. 9, pp. 211-213; abstracts, Stahl und Eisen, 1927, vol. 47, May 5, p. 764; Metallurgist, July 29, pp. 110-111; Journ. I. and S.I., 1927, No. I. p. 982).

A. Wüster and E. Piwowarsky, *A New Method for Determining the Gas Content of Liquid Metals* (Stahl und Eisen, 1927, vol. 47, Apr. 28, pp. 698-702); abstracts, Gases in Molten Iron and Steel (Metallurgist, 1927, June 24, p. 87; Journ. I. and S.I., 1927, No. I. p. 984).

E. Schiffer, *Determination of Cobalt and Impurities in Metallic Cobalt, Cobalt Steels, and Hard Cutting Alloys* (Stahl und Eisen, 1927, vol. 47, Sept. 22, pp. 1569-1571).

A. Hallbauer and P. Krüger, *Determination of Manganese in Cobalt Steels* (Zeitschrift für angewandte Chemie, 1927, vol. 40, pp. 513-514). The direct determination of manganese in alloy steel is difficult in the presence of cobalt, the separation of manganese in the usual manner not being completely satisfactory. Better results can be obtained by precipitating iron and the constituent alloy metals from a nitric acid solution of the steel with zinc oxide. The cobalt is removed from the filtrate, and the manganese can then be determined by the usual method after removal of the nitric acid.

A. P. Rollet, *On a New Colorimetric Estimation of Nickel* (Comptes Rendus, 1926, vol. 183, July, pp. 212-213). The red coloration due to the action of lead peroxide and an alkaline solution on the nickel dimethylglyoxime complex can be applied to the colorimetric estimation of nickel if oxidation be carried out by an alkaline hypochlorite or hypobromite. In the absence of cobalt and copper, the solution of nickel with a slight excess of bromine water, together with ammonia to remove the bromine, is treated with a few drops of an alcoholic solution of dimethylglyoxime. The first coloration, red tinged with orange, persists for two hours and then passes into the red shade. Very small quantities of nickel may be estimated. In the presence of cobalt, which is held in solution as sodium cobalticyanide, 10^{-2} mg. of

nickel per gramme of cobalt is shown, by comparison with a portion of the solution untreated with the dimethylglyoxime. The colorimetric test is carried out with the aid of a yellow filter (concentrated solution of cobaltcyanide). All salts of cobalt that were examined gave a positive coloration. The method is applicable to nickel steels. The dimethylglyoxime is added before the ammonia in order to prevent the adsorption of nickel by ferric oxide, which is separated by filtration.

W. Singleton, *The Determination of Vanadium in Metallurgical Products* (Chemical Age, 1927, vol. 17, July 2, pp. 1-5). Particulars are given of methods for the determination of vanadium, which are particularly applicable to ores, ferro-vanadium, and steel.

B. B. Wescott, F. E. Eckert, and H. E. Einert, *Determination of Slag and Oxides in Wrought Iron* (Industrial and Engineering Chemistry, 1927, vol. 19, Nov., pp. 1285-1288). The authors point out the need for research in the wrought iron industry. Errors are shown to exist in methods formerly used for the determination of slag and oxides. A modified method is described which is not only capable of yielding more accurate results than former methods, but may be adapted for the determination of the distribution of silicon and manganese between the base metal and slag. The modified iodine method has proved to be rapid enough for routine work, and should furnish the starting-point for research upon the chemical and physical constitution of wrought iron and their relation to fatigue and corrosion resistance.

P. Oberhoffer and E. Ammann, *Contribution to the Estimation of Oxide Inclusions in Pig Iron and Steel* (Stahl und Eisen, 1927, vol. 47, Sept. 15, pp. 1536-1540). The disadvantages of the bromine method for the determination of iron and manganese oxide are known. The present work is limited to estimating silica, silicates, and alumina. A method is described for SiO_2 , and results of SiO_2 determinations in acid and basic steels and a series of charcoal irons are given. The method was also applied to alumina, and comparative results by different processes are given. A rapid method for alumina is also described.

P. S. Brallier, *Titanous Chloride for the Determination of Iron and of Chloric Acid* (Paper read before the American Chemical Society, Jan 28-29, 1927 : Industrial and Engineering Chemistry, 1927, vol. 19, July, pp. 846-848).

K. Someya, *The Use of Liquid Amalgams in Volumetric Analysis. Part VII.—Oxidimetric Determination of Chromium* (Science Reports of the Tôhoku Imperial University, Sendai, 1927, vol. 16, pp. 397-409). The author describes a method for the quantitative reduction of chromic chloride into the chromous salt by means of zinc and lead amalgams, and some new accurate volumetric methods for the determination of chromium. A new extension in the use of Knop's diphenylamine indicator is also included.

K. Someya, *The Use of Liquid Amalgams in Volumetric Analysis. Part IX.—Some New Methods of the Determination of Vanadium and*

Tungsten (Science Reports of the Tôhoku Imperial University, Sendai, 1927, vol. 16, pp. 521-529). In this communication the author describes a method for an iodimetric and a bichromate titration of vanadium and one for a cupric sulphate titration of tungsten, the use of amalgam being involved in each case. An extension in the use of the Knop diphenylamine indicator is also included.

T. Nakazono, *Application of Liquid Amalgams to Volumetric Analysis. Part II.—Estimation of Vanadium and Uranium* (Science Reports of the Tôhoku Imperial University, Sendai, 1927, vol. 16, pp. 687-693).

N. Kanô, *Application of Liquid Amalgams to Volumetric Analysis. Part IV.—On the Use of Cadmium Amalgam* (Science Reports of the Tôhoku Imperial University, Sendai, 1927, vol. 16, pp. 701-706). The method of preparation of the cadmium amalgam and the procedure of analysis are nearly the same as those of zinc amalgam, except that the tube for receiving the amalgam after reduction is filled with dilute sulphuric acid in place of boiled water. For the determination of iron and molybdenum the reduction with cadmium amalgam was as rapid and complete as with zinc amalgam, but for those of vanadium and titanium in dilute sulphuric acid solution, as regards the completeness of the reduction, the former amalgam was somewhat inferior to the latter. The replacement of air in the reductor with carbon dioxide was found necessary for the determination of uranium with cadmium amalgam, whereas with zinc amalgam the replacement was not only unnecessary but objectionable on account of the over-reduction.

S. Kikuchi, *Application of Liquid Amalgams to Volumetric Analysis. Part V.—On the Estimation of Iron, Titanium, Uranium, and Methylene Blue* (Science Reports of the Tôhoku Imperial University, Sendai, 1927, vol. 16, pp. 707-712).

N. Kanô, *Application of Liquid Amalgams to Volumetric Analysis. Part VI.—Potentiometric Titration of Iron, Molybdenum, Uranium, Vanadium, and Titanium* (Science Reports of the Tôhoku Imperial University, Sendai, 1927, vol. 16, pp. 713-718).

S. Hakomori, *Application of Liquid Amalgams to Volumetric Analysis. Part VII.—On the Estimation of Phosphoric Acid* (Science Reports of the Tôhoku Imperial University, Sendai, 1927, vol. 16, pp. 719-722).

N. Kanô, *Application of Liquid Amalgams to Volumetric Analysis. Part VIII.—On the Estimation of Chromium and that of Iron in the Presence of Chromium* (Science Reports of the Tôhoku Imperial University, Sendai, 1927, vol. 16, pp. 723-731).

N. Kanô, *Application of Liquid Amalgams to Volumetric Analysis. Part IX.—On a New Method of Estimating Titanium and Iron in the Mixture* (Science Reports of the Tôhoku Imperial University, Sendai, 1927, vol. 16, pp. 733-738).

S. Saitô, *Application of Liquid Amalgams to Volumetric Analysis. Part X.—On the Estimation of Phosphoric Acid by Means of Uranyl Salts* (Science Reports of the Tôhoku Imperial University, Sendai, 1927, vol. 16, pp. 739-743).

Standard Chemical Samples.—*Standard Samples* (United States Bureau of Standards, 1927, Circular No. 25). The revised edition of this Circular contains a brief history of standard samples and a discussion of the function of the samples, their uses, preparation, and sales. The standard samples include analysed samples of ores, refractories, cast iron, steels, ferro-alloys, alloy steels, and other materials. A supplement to the Circular contains a complete list of the Bureau's standard samples, analyses, physical constants, weights, and cost of the standards.

Analysis of Slags and Refractories.—T. P. Colclough, *The Analysis of Silicate Slags* (Journal of the Society of Glass Technology, 1927, June, vol. 11, pp. 177–189). The author outlines general methods for the analysis of slags. Methods for routine works control are also included.

S. Shinkai, *Rapid Method for the Determination of Silica in Silicates* (Journal of the Society of Chemical Industry, Japan, 1926, vol. 29, June, pp. 67B–68B). The method is based on the fact that the addition of ammonium chloride to a silica sol transforms it into a gel. A weighed quantity of the finely divided material is fused with sodium carbonate in a platinum dish. Solution is effected by means of hydrochloric acid. The liquid is evaporated on a water-bath to a convenient bulk and 3 or 4 gm. of ammonium chloride are added; the evaporation is continued until the residue becomes a dry powder. Hot water is added to effect solution, and, after boiling to collect the silica, the liquid is settled and decanted on to a filter. Washing is effected with hot water and finally with a very weak solution of ammonium nitrate. The filter is ignited and weighed.

L. A. Sarver, *The Determination of Ferrous Iron in Silicates* (Journal of the American Chemical Society, 1927, vol. 49, June, pp. 1472–1477). Some peculiarities of diphenylamine as an indicator for the titration of ferrous iron by potassium dichromate were discussed, and it was shown that hydrofluoric acid is without effect upon it. It was also shown that hydrofluoric acid does not reduce potassium dichromate at ordinary temperatures, but does so at higher temperatures, making impossible the analysis of silicates by decomposing them in the presence of an excess of dichromate. New apparatus was designed for the decomposition, and the conditions for its use were determined.

W. J. Rees, *Notes on the Analysis of Refractories* (Journal of the Society of Glass Technology, 1927, vol. 11, June, pp. 172–176). The necessity of fine grinding of the sample is pointed out. In the case of fireclays which contained more than 2.5 to 3.0 per cent. of iron oxide and some titanite oxide, the treatment of the evaporated fusion solution at temperatures higher than 105° C. is undesirable. In the analysis of dead-burned dolomite and magnesite or magnesite bricks, solution in hydrochloric acid is frequently very slow and incomplete, and it is in such cases preferable and quicker to fuse the finely ground material with sodium carbonate, dissolve the fusion in hydrochloric acid, evaporate

to dryness on a water-bath, remove the silica, and then proceed as usual. For the determination of alumina in chrome refractories, the author recommends fusion with sodium peroxide, solution in water, and precipitation of the alumina with carbon dioxide. Disintegration of sillimanite or mullite refractories requires very prolonged fusion with sodium carbonate. The use of sodium peroxide instead of sodium carbonate is recommended as giving accurate and more rapid results.

Analysis of Fuel.—*Report of Committee D5 on Coal and Coke* (American Society for Testing Materials, June 1927). New methods are proposed for the determination of sulphur in coal and coke by the bomb-washing and sodium-peroxide fusion methods. Revision is also proposed of the standard methods of laboratory sampling and analysis of coal and coke.

J. F. Kohout, *Nitrogen as a Catalyst in the Determination of Sulphur in Coal by the Bomb-Washing Method* (Industrial and Engineering Chemistry, 1927, vol. 19, Sept., pp. 1065–1066). The effect of added nitrogen in the oxygen bomb calorimeter is to increase slightly the amount of sulphur obtained by the bomb-washing method for the determination of the sulphur in coal, and to bring the results obtained by the three methods generally used for the determination into substantial agreement. No complication in the heat value determination is introduced thereby.

W. A. Selvig and A. C. Fieldner, *Sulphur in Coal and Coke* (Paper read before the American Chemical Society, Apr. 11–16, 1927: Industrial and Engineering Chemistry, 1927, vol. 19, June, pp. 729–733). Several laboratories took part in an investigation intended to determine whether the Eschka, the bomb-washing, and the sodium-peroxide fusion methods gave comparative results for the analysis of sulphur in coal and coke. Tests were carried out on sixteen different samples. In general, the laboratories were able to obtain results with the two last-mentioned methods which checked the Eschka method sufficiently closely to show that they might be used alternately with the latter method, which has for long been the recognised standard method.

The Determination of Phosphorus in Coke (Gas World, Coking Section, 1927, vol. 87, Aug. 6, pp. 81–82). The author reviews the difficulties attending the estimation of phosphorus, touches briefly on its occurrence in coal, and describes several methods of extracting the phosphorus from the ash, going more deeply into the Fuel Research Board's method and offering a suggested modification.

D. J. W. Kreulen, *Determination of Volatile Substances in Solid Combustibles* (Chemisch Weekblad, 1926, vol. 23, Oct. 23, pp. 477–479). The author discusses a method proposed by de Waard (Chemike Weekblad, 1925, vol. 22, p. 525) for the determination of volatiles in solid fuels, which was to supersede the process known as the Bochum method. While it has certain advantages, the method is not applicable

to all fuels, and, furthermore, the furnace and conditions need rigid standardisation. The fact that the crucible must be polished before each determination is also a disadvantage.

D. J. W. Kreulen, *Determination of Water in Solid Combustibles* (Chemisch Weekblad, 1926, vol. 23, Oct. 23, pp. 476-477). The analysis of samples of Russian anthracites led the author to inquire whether there were an advantage to be derived by determining the water at temperatures above 105° C., due corrections being applied for oxidation. For purposes of precision it is preferable to adopt the xylene distillation method.

NOTICES OF RECENT BOOKS PRESENTED TO THE LIBRARY.

BULLENS, D. K. "*Steel and its Heat Treatment.*" Third edition, revised. 8vo, pp. xiii + 564, with 391 figures in the text. New York, 1927: John Wiley & Sons, Inc. London: Chapman and Hall, Ltd. (Price 25s. 0d.)

The rapid advances in the particular branch of metallurgy with which this book deals have necessitated the issue of a third edition, containing new matter and some comment on the latest practice. It is divided into three sections, or, in the author's words, phases, the first of which discusses the general principles and practice of heat-treatment processes and the variations in the structure, constitution, and character produced thereby in the steels. The second section deals with the engineering phase of heat-treatment, describing the mechanical and physical properties imparted to steel and steel alloys by different modes of treatment, into which enters a consideration of the effect of mass, with its very important influence upon results of mechanical tests. The range of alloys dealt with is a wide one, including carbon steels, nickel steels, chromium steels, chromium-nickel steels, manganese steels, vanadium and molybdenum steels, silicon steels, tungsten steels, high-speed steels, uranium, zirconium, and cerium steels, and steel castings. In the third section, or production phase, the heat-treatment operations and apparatus are described and illustrated. A detail to which hitherto not much attention has been paid is the difference between control of temperature and control of the heat-treated product, and an entire new chapter is devoted to this question, the importance of the cooling phase being likewise dwelt upon. The chapter on forging has been amplified, and new chapters have been added concerning the selection of the heating agent, whether fuel or electricity, and the selection of heat-treating equipment. This last chapter is a study of the principles which determine the choice of electrical heating equipment.

The book has long been recognised as a standard treatise on works practice in the heat treatment of steel, and the third edition, embodying the latest features of such practice, will be welcome alike to managers and operators of heat-treatment plant.

HANEMANN, H., and ANGELICA SCHRADER. "*Atlas Metallographicus: Eine Lichtbildsammlung für die technische Metallographie.*" La. 8vo. Parts 1 and 2, with 16 plates of photomicrographs (loose) and descriptive data. Berlin, 1927: Gebrüder Borntraeger. (Special subscription price, 14.25 marks.)

The compilers of this publication point out that nowhere in the extensive range of metallurgical literature is there to be found a comprehensive series of typical micrographs which may serve as standards of

comparison, so that in case of necessity every centre of metallurgical instruction is obliged to prepare its own collection. The new Metallographic Atlas is designed to meet this need by presenting reproductions of all technically important microstructures of metals for engineering purposes. The series of micrographs showing the same structure at low, up to high, magnifications, are arranged to form a number of plates which are printed in groups of 8 or 6, on loose sheets, so that the separate sheets can be conveniently used by several students working on different subjects, or they can serve as wall pictures if desired. Part I contains concise descriptions of the constituents of the specimens and explanations of the formation of the structure based on the present state of the knowledge of metallography. The first section of the work, which contains the two Parts under review, deals with carbon steels, special steels, and cast iron. A list of etching reagents and etching processes is given in the preliminary pages, and each plate is accompanied by particulars of the composition of the microspecimens shown, a description of the structure, and data concerning the treatment, etching method, and magnification. The whole series of these micrographs is based on the collection of etched specimens which have been accumulated since 1910 for instruction in metallography and constitution of materials at the Technical High School in Berlin.

It is intended that the entire series when complete shall consist of thirty similar numbers, each containing 8 plates. The subjects of the future numbers will be the following:—Pig iron, grey cast iron, chilled iron, malleable iron alloys, treatment of surfaces. These numbers will complete Section I. Section II. will deal with copper and copper alloys, the light metals, tin and lead and their alloys, nickel and nickel alloys, the precious metals, and other metals which have some technical application. The several parts can be obtained at a special subscription rate, subject to an undertaking to subscribe for the whole work, which is to consist of thirty parts. Under this scheme the present Parts 1 and 2 of Section I. are obtainable at the price of 14.25 marks.

NÁDAI, A. "*Der bildsame Zustand der Werkstoffe.*" 8vo, pp. 171, with 298 figures in the text. Berlin, 1927: Julius Springer. (Price 16.50 marks.)

The plastic state of the materials of construction—that is to say, of metals—is the subject of the work. The demands on the strength of materials of construction have increased considerably in recent years in such respects as the speed of running machinery, boiler pressures and temperatures, and the speed of vehicles. The scientific study of the properties of materials, which began in the latter part of the last century, has since continued uninterruptedly until a vast amount of information is now available concerning the plasticity and strength of metals, and this book forms a summary of the knowledge gained by the most recent scientific research. The alterations in the structure of metals due to flow has led physicists to direct their attention to the internal changes to which crystals are subject under stress. In the present work the plastic state of solid bodies is discussed, and the principles are summarised which permit of a quantitative comparison of the relations between stresses in the material on the one hand and the directions of displacement on the other. The slip surfaces afford a useful means for the interpretation of plastic deformations, and it is shown that the condition of gradual flow in solid bodies may with advantage be regarded and described as purely equilibrium conditions. These considerations form the basis of the author's study of the effect of stresses variously applied to metallic bodies of different forms.

TILLMANN, H. "*Lehrbuch der Stückzeit-Ermittlung in der Maschinenformerei.*"
8vo, pp. v + 158, with 97 figures in the text. Munich and Berlin,
1927 : R. Oldenbourg. (Price 12.50 marks.)

The book deals with the timing of operations for the purpose of fixing piece rates in the foundry, the foundry being one of those industries in which, hitherto, trustworthy methods were wanting for the estimation of the time required for the performance of the different operations involved in the making of finished castings. Such data are necessary for the acceleration of the progressive stages of the work, and the author has devoted many years to carrying out careful investigations with the object of determining the time occupied in performing every possible kind of operation connected with machine moulding. The usefulness of such information, in these days of rationalisation and simplification of both hand and mechanical operations, will certainly be appreciated by all who study the economics of the foundry trade.

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